# 5 ROTA

## 5.1 Introduction

The island of Rota, called *Luta* in the Chamorro language, is the third largest of the 14 islands of the Commonwealth of the Northern Mariana Islands (CNMI) and the fourth largest in the Mariana Archipelago with an area of 85.13 km². This island is located 62 km north of Guam and 90 km south of Tinian at 14°11′ N, 145°15′ E. Rota reaches a height of 496 m on the prominent Sabana plateau on the southwest corner of this island (Fig. 5.1a). This peak is the highest point in the

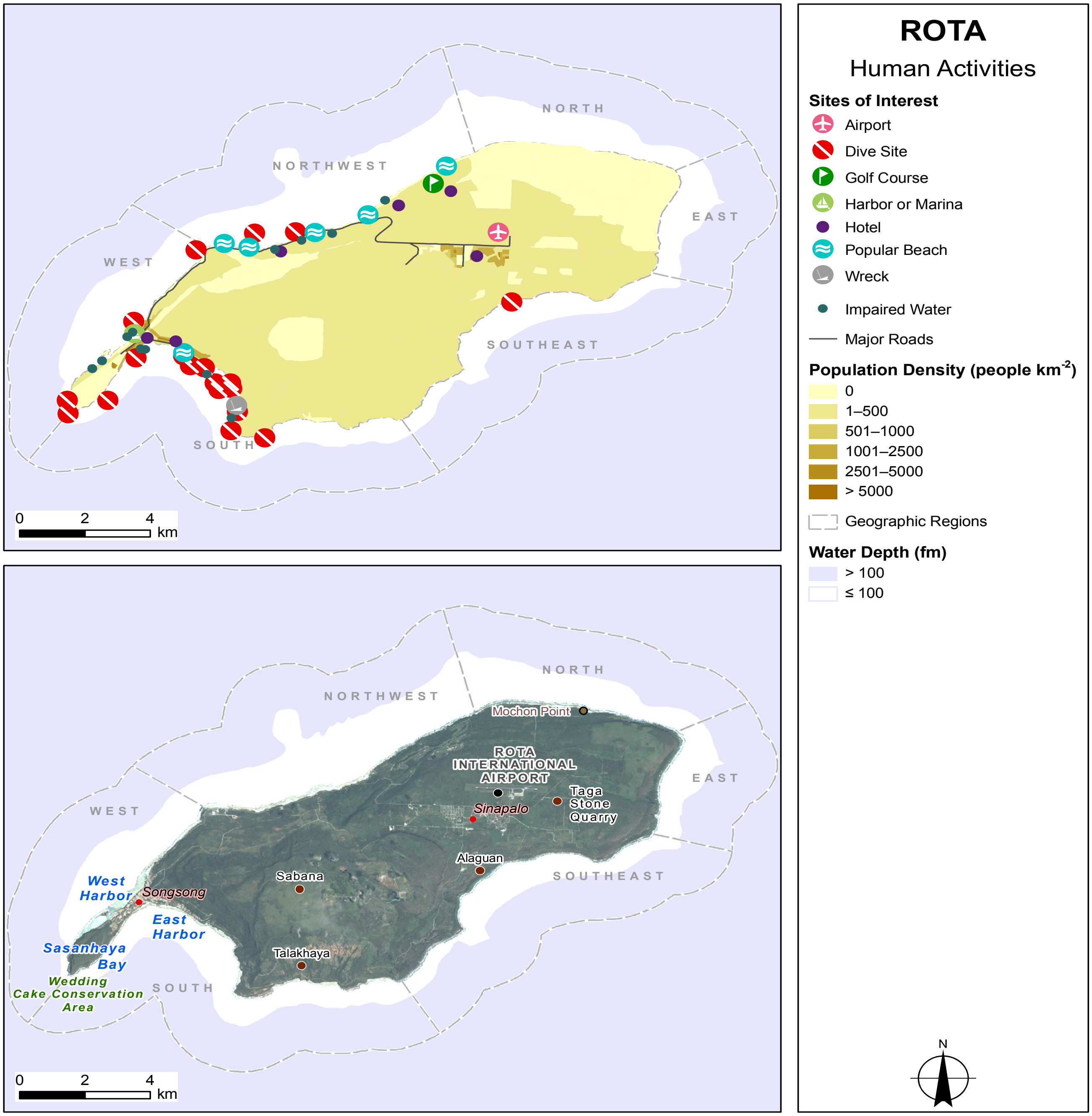



**Figure 5.1a.** Major locations of human activities (*top*) on Rota that have the potential to affect the marine environment (Bearden et al. 2008; Dive Rota; Marianas Visitors Authority 2002; Placenames.com; U.S. Geological Survey 2005b; U.S. Geological Survey) are represented over a population-density map (U.S. Bureau of the Census 2003, 2008) and (*bottom*) satellite imagery of Rota (includes material © 2005 DigitalGlobe Inc. All rights reserved), labeled with places of interest (U.S. Geological Survey).

southern Mariana Archipelago. The only rivers on Rota are located on the steep, southern flank of the Sabana plateau. On the western end of this island, a low-lying isthmus connects the main part of this island with a small terraced headland, which is called the Wedding Cake (Fig. 5.1b) because of its layered structure. Rota's coastline consists of narrow, fringing coral reefs and reef platforms with numerous patches of raised limestone benches and limestone cliffs that drop abruptly to sea. One of this island's most unique characteristics is the amount of remaining native limestone forest. Rota was not invaded during World War II (WWII), and, thus, vegetation was not destroyed as it was on Guam, Saipan, and Tinian.

**Figure 5.1b.** Wedding Cake is a flat-lying, uplifted carbonate structure on the southern shore of Rota. *NOAA photo*

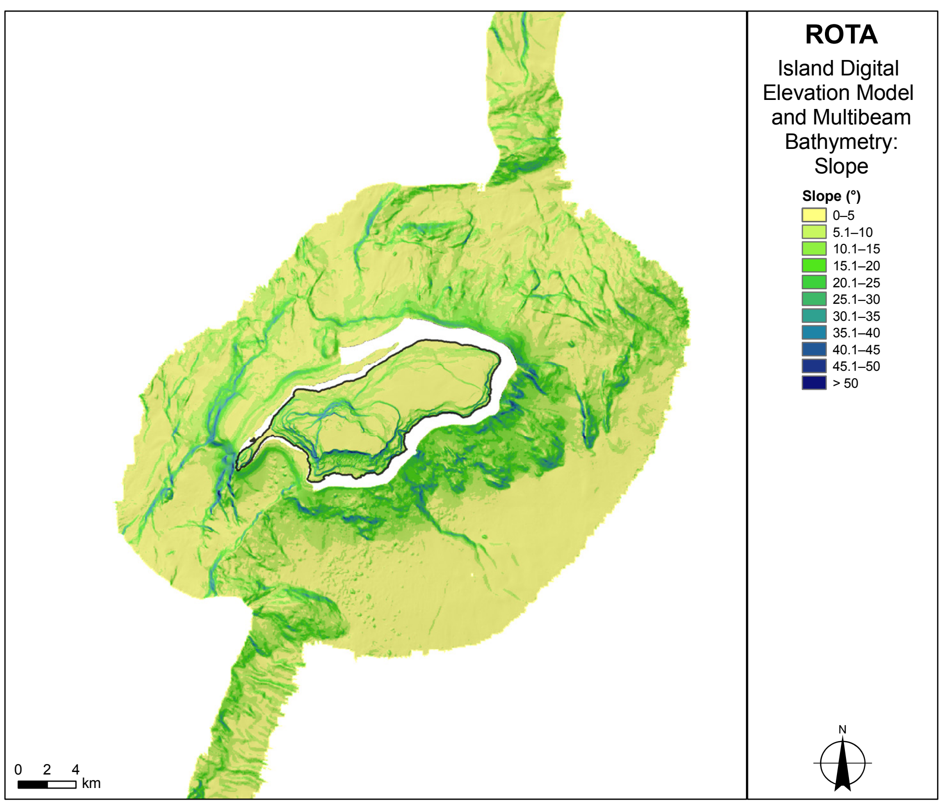



**Figure 5.1c.** Combined slope map using the digital elevation model and multibeam bathymetric data for Rota.

Rota is the smallest of the 3 southern, inhabited islands in the CNMI, both in size and population. This island's primary population centers are Songsong on the southwestern peninsula and Sinapalo, a village south of Rota International Airport on the eastern side of this island. Two harbors, West Harbor and East Harbor, lie on either side of this island's peninsula. One major hotel, the Rota Resort and Country Club, is located on the northwest side of Rota and has an 18-hole golf course near the shoreline. This resort also has one of the only large wetland areas on Rota; other smaller wetlands are scattered around this island. About 7 other small hotels or motels are located on Rota. The transition of land use from public to private ownership that has been occurring over several decades is expected to continue: in 2005, land that was flat or of low slopes (Fig. 5.1c) and most suitable to development made up 66% of Rota's land, and at least 75% of that land was or was expected to soon be privately owned (National Park Service [NPS] 2005). The remaining 34% of land on Rota consists of cliffs or steep slopes (Fig. 5.1c), areas that contain a majority of the remaining undisturbed native forests (NPS 2005).

### 5.1.1 History and Demographics

Rota was first populated when the Chamorro arrived about 3500 year ago and has been continuously inhabited since then. This island contains the best remaining examples of what is known as the Latte Phase (AD 1100–1521) of the cultural tradition of the Chamorro people of the Mariana Archipelago (Fig. 5.1.1a). The Latte Phase is named for the distinctive limestone architectural elements that began to appear throughout this archipelago ~ 800–1000 years ago. Rota has 2 well-preserved ancient Chamorro villages, 1 at Mochon Point on the north coast and 1 at Alaguan on the southeast coast. Other architectural elements include an intact latte stone quarry, the Taga Stone Quarry, near the eastern end of the airport and a cave along the east coast with pictographs showing ancient Chamorro rock art (NPS 2005). Fishing and agriculture were the foundations of the pre-historic Chamorro economy (Rogers 1995). Archeological evidence on Rota shows that some areas were terraced in ancient times for the cultivation of rice and taro (NPS 2005).

**Figure 5.1.1a.** The latte stone quarry at Taga on Rota. *Photo by Christopher T. Snow,* available under a Creative Commons license on Flickr (http://www.flickr.com/photos/ctsnow/95312116).

ROTA

The islands of the Mariana Archipelago were claimed by Spain in 1565. An estimated 24,000 to 30,000 Chamorro remained on all islands of this archipelago in 1668, but by 1710 the Chamorro population plummeted to just over 3500 on Guam and Rota because of epidemics and conflicts with the Spanish (Rogers 1995). Because the indigenous Chamorro population of Rota dropped significantly during the 200 years of occupation by Spain, the native vegetation recovered, even on areas that had been completely cleared for subsistence agriculture.

Rota and Guam were the only islands of the Mariana Archipelago that were continuously populated during the period of rule by Spain from 1521 to 1899, because Spain relocated all Chamorro from the northern islands to these 2 islands. Like most of the other islands of the Mariana Archipelago, Rota was under rule by Germany from 1899 to 1914, when all of this archipelago's islands except Guam became a protectorate of Japan. In the 1920s and 1930s, the Japanese developed phosphate mining and sugar plantations on Rota. An estimated 60% of land on Rota was cleared of native forest for these sugar plantations, and later, during WWII, the Japanese built defensive fortifications and roads to all parts of this island (NPS 2005). The Allied Forces did not invade Rota during WWII; thus, some of the best-preserved Japanese fortifications in the Mariana Archipelago are found on Rota, which the Japanese surrendered to the United States on September 2, 1945. The social changes and economic developments that have taken place on and reshaped Guam, Saipan, and Tinian since the end of WWII have had comparatively little effect on Rota.

The human population on Rota in 2010 was 2527, a 23% drop from the estimate made in 2000 but nearly double the population estimate for 1980 (U.S. Bureau of the Census 1983, 2011a). Despite the decline between to the two most recent U.S. Census estimates, Rota in 2010 still made up ~ 5% of the total CNMI population, as it had in 2000 (Fig. 5.1.1b; U.S. Bureau of the Census 2011a). The overall decline in the CNMI's population is related partly to a fall in tourism (Fig. 5.1.1b) caused by a weak worldwide economy and the demise of the garment industry on Saipan.

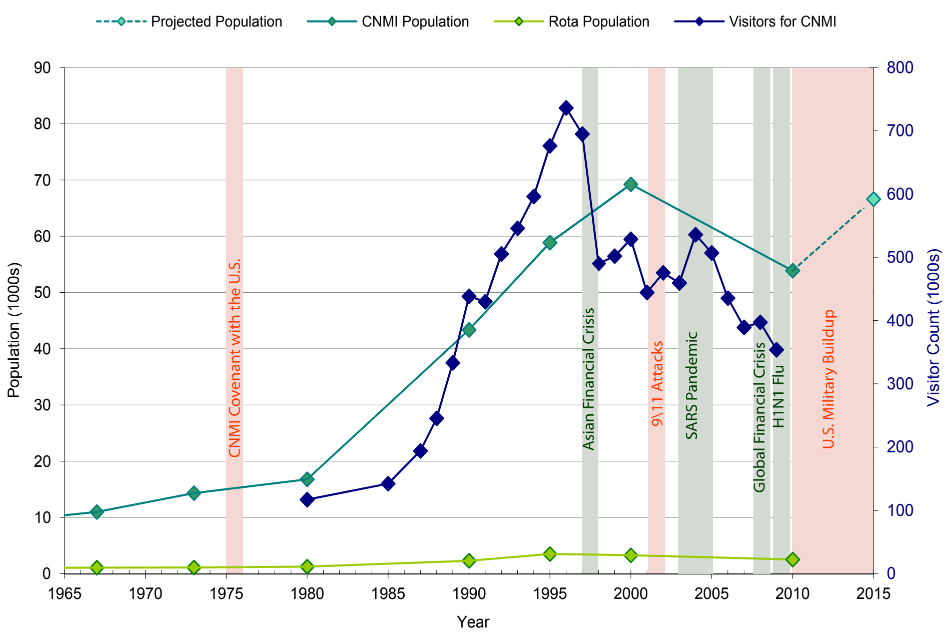



**Figure 5.1.1b.** Population growth (U.S. Census Bureau 2003, 2011a; CNMI Department of Commerce 2002a; Secretariat of the Pacific Community 2011) and visitor count (Bank of Hawaii 1995; Lucas et al. 1990; U.S. Department of the Interior 1996; CNMI Department of Commerce 2002b; Marianas Visitors Authority) trends on Rota and in the CNMI during the period of 1965–2015.

## 5.1.2 Geography

Like Saipan, Tinian, Aguijan and Guam, the island of Rota is composed of a series of coralline limestone terraces that rise one above the other. These limestone terraces lie on top of a volcanic core, which emerges from these terraces in only a few places on the southern side of this island on the Sabana plateau. No comprehensive geologic studies have been carried out on Rota, and no geologic map exists. However, Keel et al. (2005) studied the karst geomorphology of Rota and mapped 120 caves on this island.

The Sabana plateau is the center of Rota's primary watershed. There, the volcanic core is exposed for ~ 0.25 km² along the steep, dissected slopes of this island's south coast, where all of the surface streams on Rota are located. Water emerges at an elevation of ~ 335 m, and many contact caves are found where porous limestone meets the impermeable volcanic core (Keel et al. 2005).

### 5.1.3 Economy

Tourism is the principal economic industry on Rota, and the service sector accounts for ~ 50% of employment on this island (Fig. 5.1.3a). Visitors to Rota currently make up only about 2% of the total visitors to the CNMI (CNMI Department of Commerce 2002b). However, business leaders consider tourism the most promising industry for the future, and, in October 2009, the governor's office announced that an investor is planning a new casino complex and water bottling plant there (CNMI Office of the Governor 2009). Many small-scale subsistence farms operate throughout Rota. Some large-scale farms and ranches exist, especially on the eastern part of this island. However, limestone soils on Rota are not well suited for either agriculture or grazing (NPS 2005). Community farms are present on the highest plateau of the Sabana watershed, but most of the farming in this area has been discontinued in recent years because of concerns about adverse impacts to the domestic water supply (NPS 2005). In 2008, a shrimp farm was established on Rota, the second site in the nascent aquaculture industry in the CNMI.

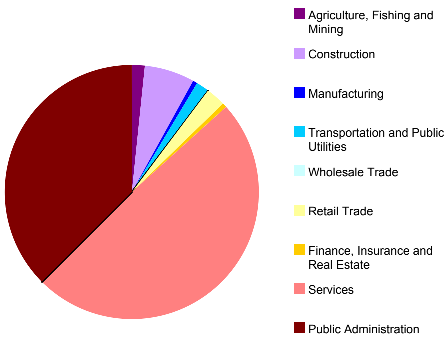



**Figure 5.1.3a.** Employment by sector on Rota in 2005 (CNMI Department of Commerce 2008). The services category includes professional services, education, health and social services, arts and entertainment, and recreation.

The 1996 Rota Economic Master Plan emphasized the importance of some of Rota's environmental and cultural attributes, not only to the people of Rota but also to the entire CNMI, and of conserving these attributes. This plan pointed out that tourism would benefit from the conservation of parts of the environment on Rota. Recent studies have found that Rota's natural and cultural values would be ideally suited for the development of ecotourism. (NPS 2005)

The CNMI Comprehensive Economic Development Strategic Plan for 2009–2014 (Comprehensive Economic Development Strategy [CEDS] Commission 2009) noted that one of the challenges for the CNMI government is the provision of infrastructure for power, water, sewage, and other public services on 3 major islands, of which Rota is the smallest and least economically developed. In addition, a weak global economy, rising fuel prices, and falling tourism rates have resulted in a 40% decrease in revenue in the CNMI from $248 million in 2006 to a projected $154 million in 2009. This plan proposes a number of projects to improve the Rota economy, including those listed below that may have potential impacts on the coral reef ecosystems:

- Rehabilitation of West Harbor
- Construction of a fuel farm at Rota International Airport
- Widening of the airport runway
- Relocation of the sanitary landfill
- Construction of a sewage treatment plan
- Significant enlargement of Rota's West Harbor to make this island's agricultural industry competitive (local farmers on Rota have developed a number of root and other crops that are available for export, but equipment and transportation infrastructure is lacking)
- Enhancement of tourism facilities, including opening up and preserving additional ancient Chamorro sites through a grant and building up beach and water sport parks through private partnerships
- Construction of a casino

### 5.1.4 Environmental Issues on Rota

Native limestone forest now covers well over half of this island (Fig. 5.1.4a). A 1976 survey by the U.S. Forest Service identified 12,147 acres of native limestone forest on Rota but only 1714 and 1182 acres on the larger islands of Tinian and Saipan (NPS 2005). The lower limestone terraces on the southeastern side of the Sabana plateau contain native forest in good condition with some extremely rare trees. Mid-elevation limestone terraces also contain native forest in good condition, and, on the upper limestone terraces, forest changes to a wetter, luxuriant type of vegetation with a full canopy. A considerable area on the southwestern summit of the Sabana plateau is pitted and pinnacled, a result of phosphate mining during the period of Japanese rule (NPS 2005).

Wildfires intentionally set by hunters have damaged the Talakhaya Watershed (Fig 5.1.4a) for decades. Hunters set fires because they want to attract the Sambar deer (*Cervus unicolor*) by creating new vegetation growth. These fires eliminate established vegetation and devastate habitat, causing considerable soil erosion and slumping, especially during the rainy season of July to September, leading to significant sedimentation in adjacent marine environments and freshwater streams. Since 2006, Rota schools have participated in revegetation efforts in the Talakhaya area (Saipan Tribune 2007).

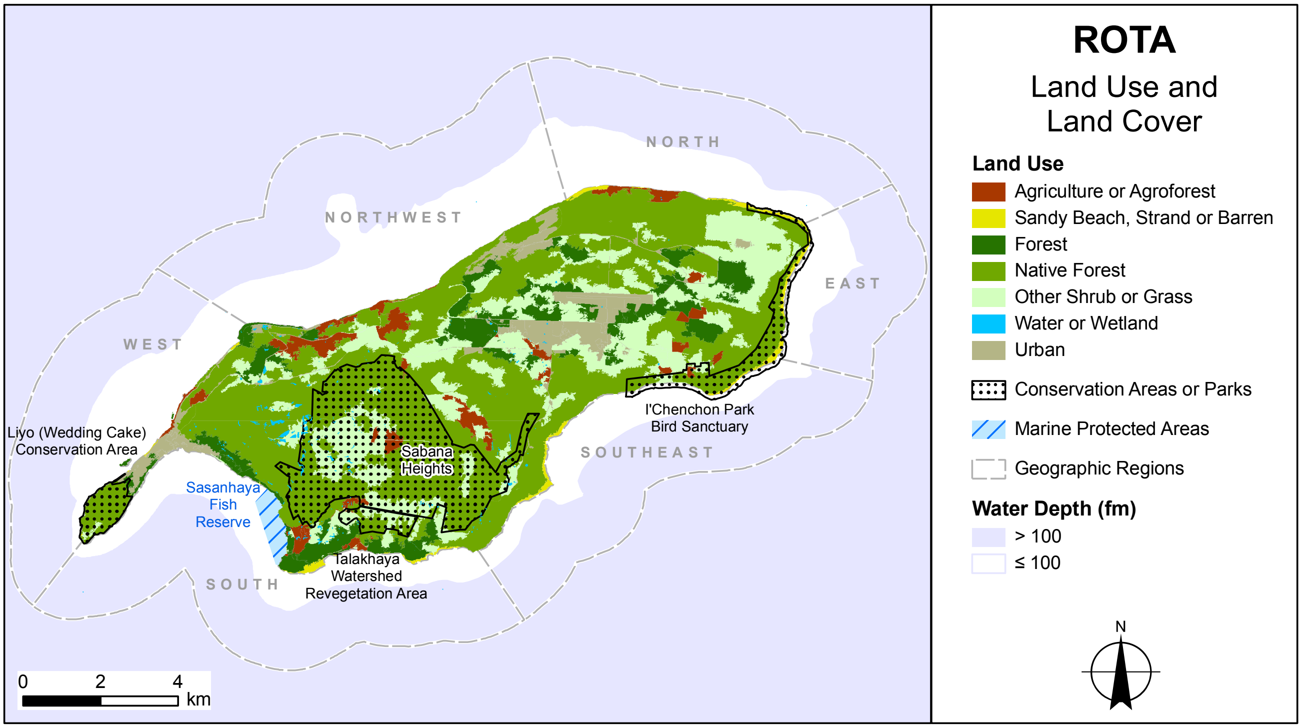



**Figure 5.1.4a.** Land use, conservation areas, parks, and marine protected areas (MPAs) on Rota are represented over a vegetation cover map (Liu and Fisher 2006).

Rota has 2 tree species and 1 herbaceous species that are Federally listed as endangered (U.S. Fish and Wildlife Service), and few specimens of any of these 3 species remain. Three introduced ungulates, Philippine deer (*Rusa Marianna*), feral pig, and domestic cattle are thought to play a role in the destruction of these tree species. Three bird species, the Mariana crow (*Corvus kubaryi*), Rota bridled white-eye (*Zosterops rotensis*), and Mariana common moorhen (*Gallinula chloropus guami*), are Federally listed as endangered, and the Mariana fruit bat (*Pteropus mariannus mariannus*) is listed as threatened (U.S. Fish and Wildlife Service). All 4 of these species are listed locally as threatened or endangered (Berger et al. 2005). Analysis conducted by the CNMI Division of Fish and Wildlife (DFW) has shown that most other bird populations on Rota also have declined substantially over the past few decades (NPS 2005). One issue is introduction of the brown tree snake (*Boiga irregularis*) from Guam, which is only 62 km south of Rota, and the potential threat it posed to all birds on this island (Fritts and Leasman-Tanner 2001; Marianas Avifauna Conservation Working Group 2008). The CNMI DFW sponsors extensive efforts to minimize the risk of brown tree snake introduction.

Both the green sea turtle (*Chelonia mydas*) and hawksbill sea turtle (*Eretmochelys imbricata*) are Federally listed as endangered in the Mariana Archipelago and locally listed as threatened or endangered (U.S. Fish and Wildlife Service; Berger et al. 2005). Few green turtles and no hawskbills have been documented as nesting on Rota in recent years. Rota is an important habitat for several species of sea birds, including the red-footed booby (*Sula sula*), brown booby (*Sula leucogaster*), white (fairy) tern (*Gygis alba*), great frigatebird (*Fregata minor*), brown noddy (*Anous stolidus*), and white-tailed tropic bird (*Phaethon lepturus*).

Major portions of public lands on Rota and their natural resources are currently protected under CNMI and local laws, including Rota Local Law Nos. 9-1, 9-2, 9-3, and 15-8, as watersheds, sea bird sanctuaries, or conservation areas for forests and wildlife (Fig. 5.1.4a; NPS 2005):

- I`Chenchon Park Bird Sanctuary on this island's eastern coastline is the largest sea bird nesting colony in the Mariana Archipelago.
- Sasanhaya Fish Reserve, a no-take zone on the southern shore of Rota, was the first marine protected area (MPA) designated in the CNMI.

- Coral Gardens Marine Reserve is a biological reserve at the eastern end of Sasanhaya Bay that extends out to a depth of ~ 30 m.
- Sabana Protected Area, which covers a high plateau area (Sabana Heights) in the southwestern portion of this island, was established to provide watershed protection and wildlife and forest conservation as well as allow for community farming, hunting, and medicinal plant gathering.
- Talakhaya Watershed Revegetation Area contains Rota's only flowing waters and serves as the major source for this island's public water supply.
- Liyo (Wedding Cake) Conservation Area at the western tip of this island is a wildlife protection area where no take is allowed of plant or animal species.
- Small cultural sites, such as Mochon prehistoric village and Taga Stone Quarry, are managed by the Historic Preservation Office.

Several specific environmental issues have been identified on Rota, including the ones listed here:

- Non-point pollution from soil erosion on the south side of the Sabana plateau in the Talakhaya region, which was stripped as part of phosphate mining by the Japanese and is subject to fires set by hunters. Coral reefs along this coastline show signs of decreasing health caused by significant soil and debris deposition originating from that upland erosion (NPS 2005).
- There has been little enforcement at the Sasanhaya Fish Reserve. Unpublished research from the CNMI's DFW suggests that fisheries recovery rates at this reserve are lower than at other MPAs where no-take rules have been more consistently enforced (Starmer et al. 2008).
- The current refuse disposal site on Rota is an open-air dump, and no heavy equipment is available at the landfill to properly maintain, reposition, and operate this existing landfill. An alternative site has not been finalized, but this "dump must be closed" (CEDS Commission 2009).
- Rota's primary sources of drinking water as of 1995 were exceeding standards set by the federal *Safe Drinking Water Act* (CEDS Commission 2009).
- Upgrades to Rota's sewer system are needed. This variable-grade sewer system serves only a portion of the Songsong village. Gravity and septic sewers serve the remainder of Songsong and other villages (CEDS Commission 2009).
- Upgrades to roads around this island are needed to reduce sediment runoff and improve transportation. Currently, only 19.3 of the 140 km of road on Rota are paved, and 48.3 km are classified as "improved" (CEDS Commission 2009).
- Rota storm drainage improvements could be included as part of the design and construction of roads to incorporate ground absorption infiltrators and retention ponds. The current system uses a combination of gutters, ditches, and cross-gutters. Paving village streets is part of a proposed solution for drainage (CEDS Commission 2009).

## 5.2 Survey Effort

Biological, physical, and chemical observations collected under the Mariana Archipelago Reef Assessment and Monitoring Program (MARAMP) have documented the conditions and processes influencing coral reef ecosystems around the island of Rota since 2003. The spatial reach and time frame of these survey efforts are discussed in this section. The disparate areas around this island often are exposed to different environmental conditions. To aid discussions of spatial patterns of ecological and oceanographic observations that appear throughout this chapter, 6 geographic regions around Rota are delineated in Figure 5.2a; wave exposure and breaks in survey locations were considered when defining these geographic regions. This figure also displays the locations of the Rapid Ecological Assessment (REA) surveys, towed-diver surveys, and towed optical assessment device (TOAD) surveys conducted around Rota. Potential reef habitat around this island is delineated by the 100-fm contour and shown in white on this map.

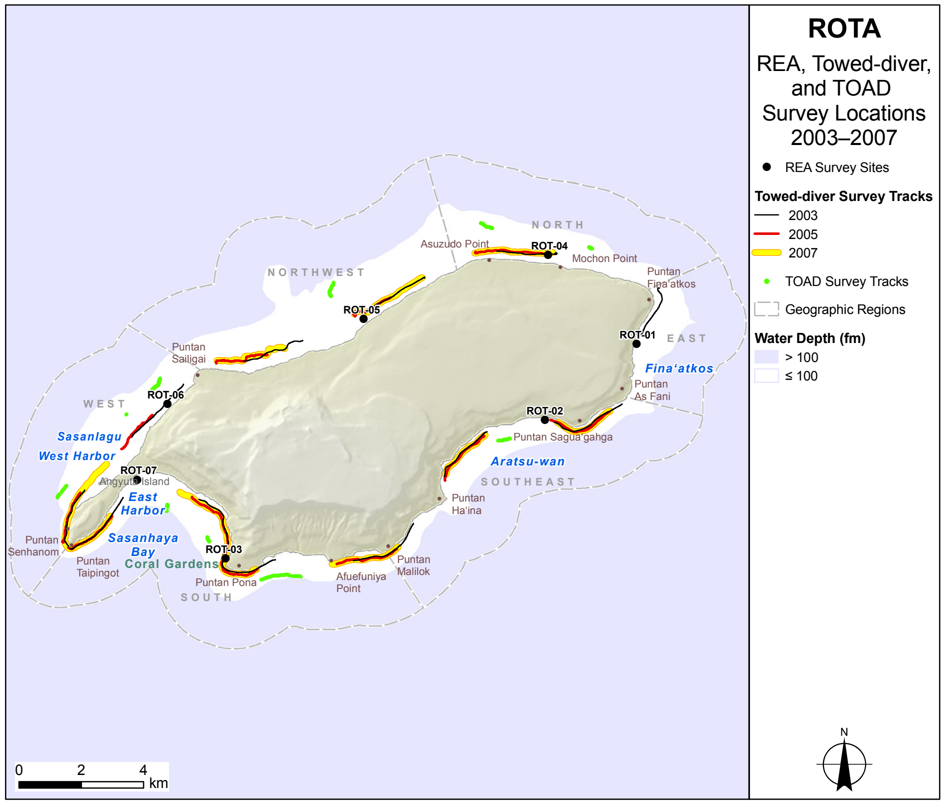



**Figure 5.2a.** Locations of REA, towed-diver, and TOAD benthic surveys conducted around Rota during MARAMP 2003, 2005, and 2007. To aid discussion of spatial patterns, this map delineates 6 geographic regions: north, east, southeast, south, west, and north-west.

Benthic habitat mapping data were collected around Rota using a combination of acoustic and optical survey methods. MARAMP benthic habitat mapping surveys conducted around this island with multibeam sonar covered a total area of 5.1 km$^2$ in 2003 and 800 km$^2$ in 2007. Optical validation and habitat characterization were completed using towed-diver and TOAD surveys that documented cover of live hard corals, sand cover, and habitat complexity. The results of these efforts are discussed in Section 5.3: “Benthic Habitat Mapping and Characterization.”

Information on the condition, abundance, diversity, and distribution of biological communities around Rota was collected using REA, towed-diver, and TOAD surveys. The results of these surveys are reported in Sections 5.5–5.8: “Corals and Coral Disease,” “Algae and Algal Disease,” “Benthic Macroinvertebrates,” and “Reef Fishes.” The numbers of surveys conducted during MARAMP 2003, 2005, and 2007 are presented in Table 5.2a, along with their mean depths and total

**Table 5.2a.** Numbers, mean depths (m), total areas (ha), and total length (km) of REA, towed-diver, and TOAD surveys conducted around Rota during MARAMP 2003, 2005, and 2007. REA survey information is provided for both fish and benthic surveys, the latter of which includes surveys of corals, algae, and macroinvertebrates.

| Survey Type | Survey Detail | Year | | |
|---|---|---|---|---|
| **REA** | | **2003** | **2005** | **2007** |
| Fish | Number of Surveys | 6 | 6 | 6 |
| | Mean Depth (m) | 12.4 (SD 0.6) | 11.7 (SD 2.1) | 11.7 (SD 2.1) |
| Benthic | Number of Surveys | 6 | 6 | 6 |
| | Mean Depth (m) | 12.4 (SD 0.6) | 11.7 (SD 2.1) | 11.7 (SD 2.1) |
| **Towed Diver** | | **2003** | **2005** | **2007** |
| | Number of Surveys | 12 | 11 | 10 |
| | Total Survey Area (ha) | 26.3 | 21.4 | 23.2 |
| | Mean Depth (m) | 12.6 (SD 1.6) | 16.1 (SD 1.2) | 15.9 (SD 1.2) |
| **TOAD** | | **2003** | | |
| | Number of Surveys | 10 | | |
| | Total Length (km) | 4.13 | | |

areas or length. For surveys of reef fishes, belt-transect surveys were conducted at 5 REA sites and stationary-point-count surveys were done at 1 additional site (only belt-transect data are provided in this report).

Spatial and temporal observations of key oceanographic and water-quality parameters influencing reef conditions around Rota were collected using (1) two types of moored instruments designed for long-term observations of high-frequency variability of temperature, (2) closely spaced conductivity, temperature, and depth (CTD) profiles of the vertical structure of water properties, and (3) discrete water samples for nutrient and chlorophyll-*a* analyses. CTD casts were conducted during MARAMP 2003, 2005, and 2007, and water sampling was performed during MARAMP 2005 and 2007. Results for some casts and water samples are not presented in this report because either the data were redundant or erroneous or no data were produced (see Chapter 2: "Methods and Operational Background," Section 2.3: "Oceanography and Water Quality"). A summary of deployed instruments and collection activities is provided in Table 5.2b, and results are discussed in Section: 5.4: "Oceanography and Water Quality."

**Table 5.2b.** Numbers of oceanographic instruments deployed, shallow-water and deepwater CTD casts performed, and water samples collected around Rota during MARAMP 2003, 2005, and 2007. Two types of instruments were moored at Rota: sea-surface temperature (SST) buoy and subsurace temperature recorder (STR). Shallow-water CTD casts and water samples were conducted from the surface to a 30-m depth, and deepwater casts were conducted to a 500-m depth. Additional deepwater CTD cast information is presented in Chapter 3: "Archipelagic Comparisons."

| Observation Type | Year | | | | | | |
|---|---|---|---|---|---|---|---|
| Instruments | 2003 | 2005 | | 2007 | | 2009 | Lost |
| | Deployed | Retrieved | Deployed | Retrieved | Deployed | Retrieved | |
| SST | 1 | – | 1 | 1 | 1 | – | 2 |
| STR | – | – | 2 | 2 | 3 | 1 | 1 |
| **CTD Casts** | **2003** | **2005** | | **2007** | | | **Total** |
| Shallow-water Casts | 21 | 28 | | 29 | | | 78 |
| Deepwater Casts | – | 4 | | 3 | | | 7 |
| **Water Samples** | | **2005** | | **2007** | | | **Total** |
| | | 4 | | 5 | | | 9 |

### *Towed-diver Surveys: Depths*

Figures 5.2b–e illustrate the locations and depths of towed-diver-survey tracks around Rota and should be referenced when further examining results of towed-diver surveys from MARAMP 2003, 2005, and 2007.

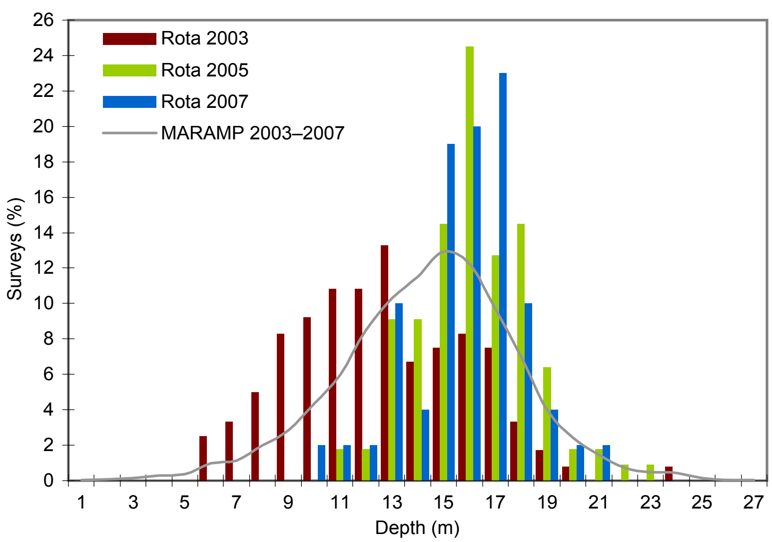
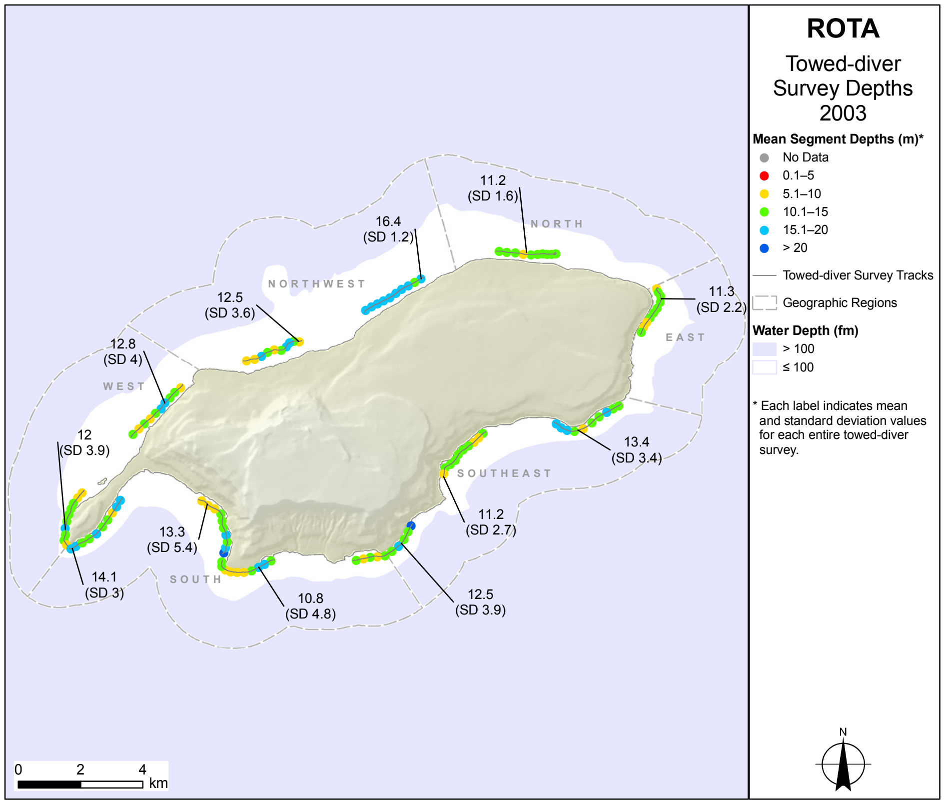



**Figure 5.2b.** Depth histogram plotted from mean depths of 5-min segments of towed-diver surveys conducted on forereef habitats around Rota during MARAMP 2003, 2005, and 2007. Mean segment depths were derived from 5-s depth recordings. Segments for which no depth was recorded were excluded. The grey line represents average depth distribution for all towed-diver surveys conducted around the Mariana Archipelago during MARAMP 2003, 2005, and 2007.

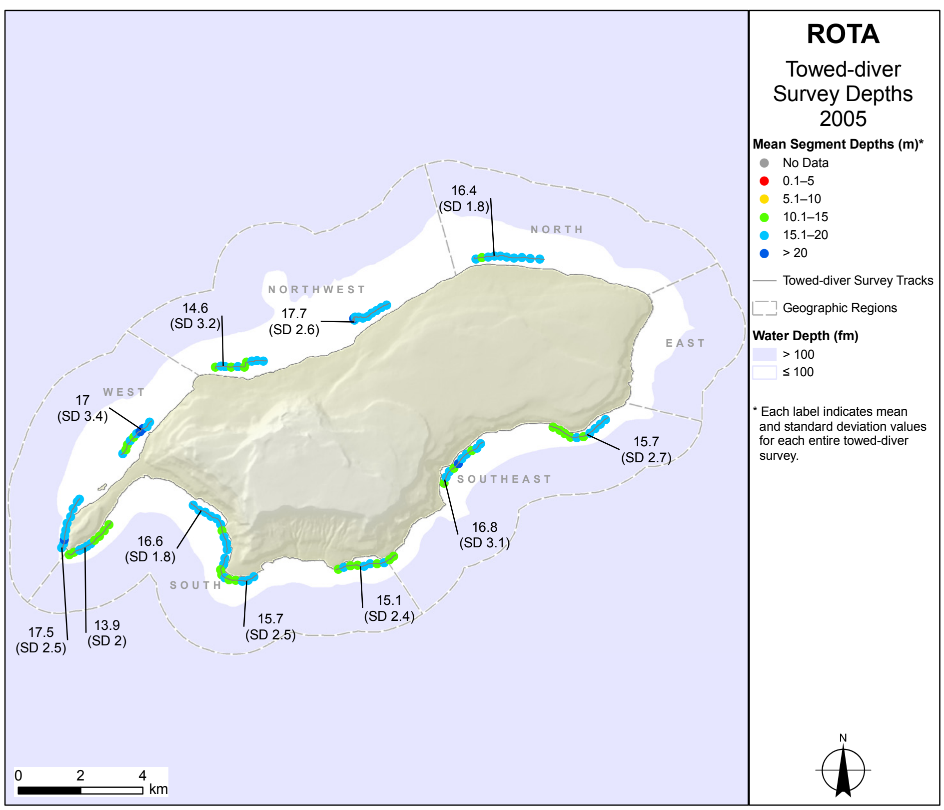
During MARAMP 2003, 12 towed-diver surveys were conducted along the forereef slopes around most of Rota (Figs. 5.2b and c). The mean depth of all survey segments was 12.6 m (SD 1.6), and the mean depths of individual surveys ranged from 10.8 m (SD 4.8) to 16.4 m (SD 1.2).

**Figure 5.2c.** Depths and tracks of towed-diver surveys conducted on forereef habitats around Rota during MARAMP 2003. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate.




During MARAMP 2005, 11 towed-diver surveys were conducted along the forereef slopes in most geographic regions of Rota (Figs. 5.2b and d). The mean depth of all survey segments was 16.1 m (SD 1.2), and the mean depths of individual surveys ranged from 13.9 m (SD 2) to 17.7 m (SD 2.6).

**Figure 5.2d.** Depths and tracks of towed-diver surveys conducted on forereef habitats around Rota during MARAMP 2005. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate.



During MARAMP 2007, 10 towed-diver surveys were conducted along the forereef slopes around most geographic regions of Rota (Figs. 5.2b and e). The mean depth of all survey segments was 15.9 m (SD 1.2), and the mean depths of individual surveys ranged from 13.5 m (SD 2.9) to 17.5 m (SD 4.1).

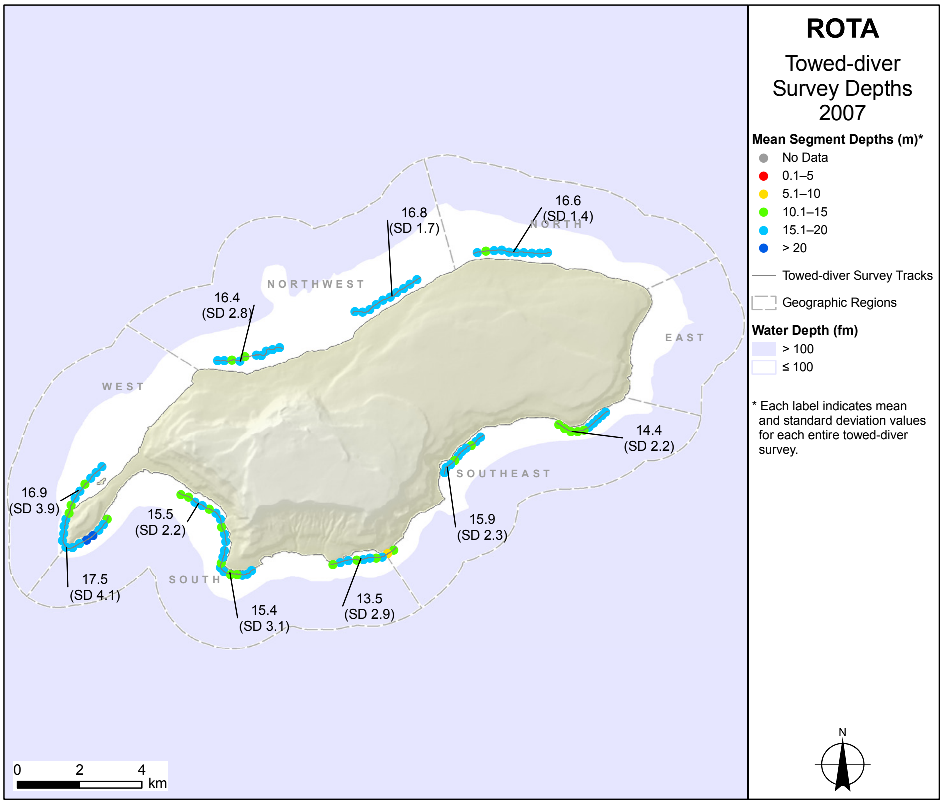



**Figure 5.2e.** Depths and tracks of towed-diver surveys conducted on forereef habitats around Rota during MARAMP 2007. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate.

## 5.3 Benthic Habitat Mapping and Characterization

Benthic habitat mapping and characterization surveys around the island of Rota during MARAMP 2003, 2005, and 2007 were conducted using acoustic multibeam sonar, underwater video and still imagery, and towed-diver observations. Acoustic multibeam sonar mapping provided bathymetric and backscatter data products over the depth range of 1–1800 m. Optical validation and benthic characterization, via diver observations and both video and still underwater imagery, were performed at depths < 188 m.

### 5.3.1 Acoustic Mapping

Multibeam acoustic bathymetry and backscatter imagery (Fig. 5.3.1a) collected by the Coral Reef Ecosystem Division (CRED) around Rota during MARAMP 2003 and 2007 encompassed an area of 805.1 km$^2$. Because of a lack of time, acquisition of high-resolution multibeam data was limited in extent, covering only parts of the northwest, west, and south geographic regions. Multibeam data of lower resolution were obtained with the 30-kHz Kongsberg EM 300 sonar on the NOAA Ship *Hi`ialakai*, providing complete coverage to a depth of 1275 m west of Rota and a depth of 1800 m to the east.

Multibeam bathymetry acquired around Rota reveals a fairly irregular topography, with many scarps, ridges, and canyons (Fig. 5.3.1a, top panel). North of Rota a series of ridges are observed radiating away from this island, with narrow canyons formed between them. Scarps and fissures at depths of 800–1400 m run at various orientations, with 2 longer, more prominent scarps running southwest–northeast, and another 2 running southeast–northwest.

Southwest of Rota, three scarps run on a northeast–southwest orientation. On the more gentle slopes on the back of the scarps, the bathymetry shows fissures cutting into otherwise smooth slopes. The seabed south of Rota is littered with large blocks of material that probably result from mass-wasting (movement of soil and surface materials by gravity).

The seabed east of Rota descends much more steeply from the coast in comparison to north, west and south of this island, with the depth of 1000 m reached within 2.5–4 km of the coast. Here, narrow ridges descend to 1500 m, forming wide, curved canyons. Below this area, the seabed descends more gradually.

Backscatter data collected around Rota show clear patterns, with marked areas of higher and lower backscatter intensity (Fig. 5.3.1a, bottom panel). Some of the broader patterns can be clearly related to features in the topography; however, some of the finer-scaled patterns are more difficult to interpret. A wide swath of low-intensity backscatter is shown north of Rota, indicating a large area of soft sediments. East of this low-intensity swath, an area of seabed marked with fissures

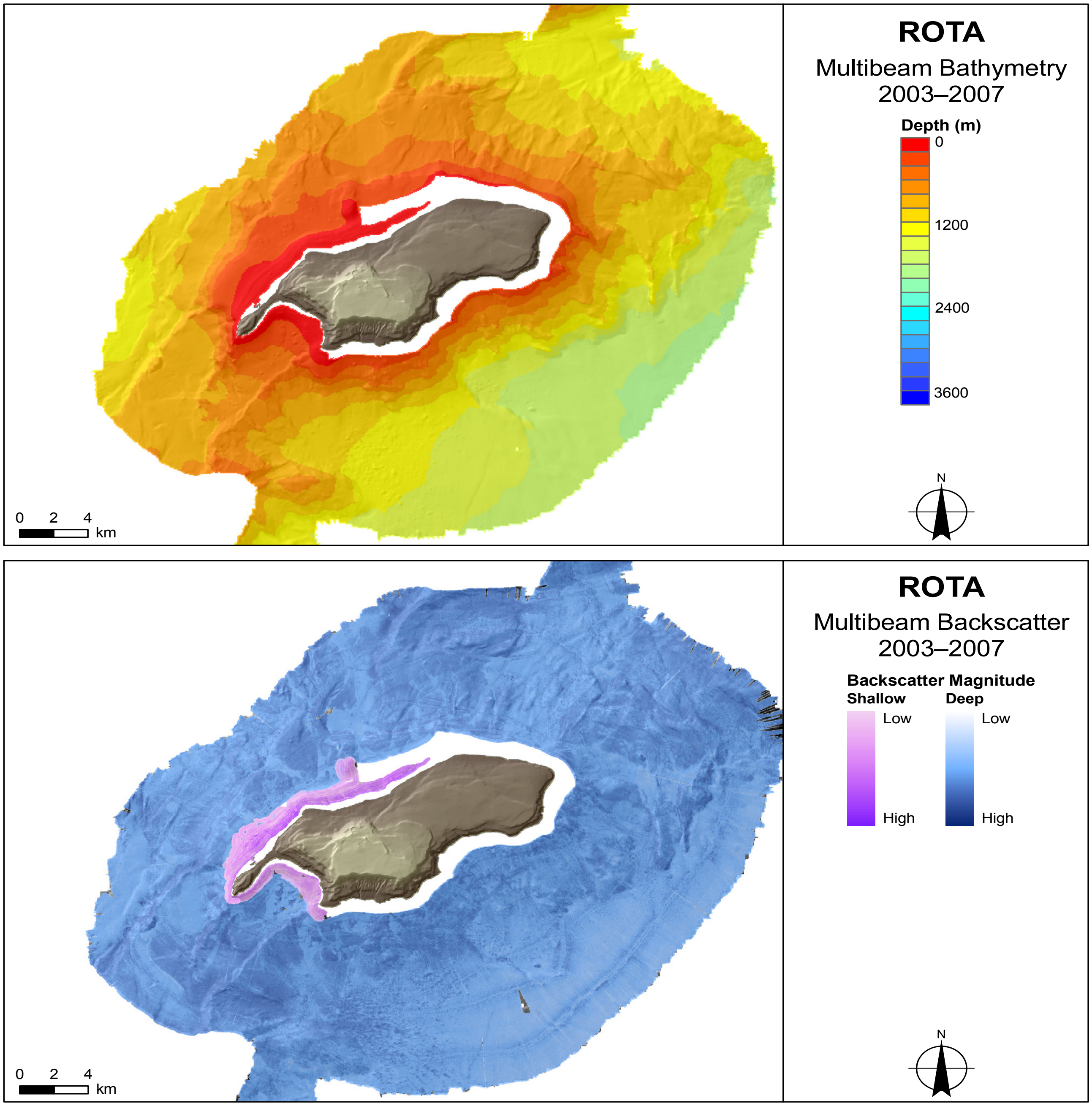



**Figure 5.3.1a.** Gridded (*top*) multibeam bathymetry (grid cell size: 60 m) and (*bottom*) backscatter (grid cell size: 5 m) collected around Rota during MARAMP 2003 and 2007 at depths of 1–1800 m. Shallow-backscatter data (shown in purple) were collected using a 240-kHz Reson SeaBat 8101 ER sonar, and deep-backscatter data (shown in blue) were collected using a 30-kHz Kongsberg EM 300 sonar. Light shades represent low-intensity backscatter and may indicate acoustically absorbent substrates, such as unconsolidated sediment. Dark shades represent high-intensity backscatter and may indicate consolidated hard-bottom or coral substrates.

and scarps is revealed to have higher-intensity backscatter, suggesting that within this area, the seabed is characterized by harder substrates. North of Rota, a flat-bottomed channel is likely to be characterized by soft sediments, as suggested by the low backscatter values recorded there. One of the scarps running southwest of Rota has a clear band of high-intensity backscatter, which runs along the scarp edge, suggesting that this area may have hard substrates at or near the seabed surface, in comparison to the more gentle slopes on the back of the scarps, where lower backscatter values were recorded. Variations in backscatter intensity observed south of Rota are less distinct, and despite the clear topographic features observed in the bathymetry in this area, it is not possible to clearly relate these features to changes in backscatter.

### *Multibeam Bathymetry and Derivatives*

High-resolution multibeam data collected in nearshore (depths of 0–800 m) waters around Rota (Fig. 5.3.1b) were gridded at a 5-m resolution to allow for the identification of fine-scaled features. These high-resolution data have also been used to derive maps showing slope (Fig. 5.3.1c), rugosity (Fig. 5.3.1d), and bathymetric position index (BPI) zones (Fig. 5.3.1e). Together, these maps provide layers of information to characterize the benthic habitats around Rota.

Because of the limited time available to survey Rota, the coverage of high-resolution bathymetry data focused on the west and south of this island. To provide a more complete picture of the seabed character around Rota, the low-resolution (60-m grid) multibeam data also have been used to derive maps showing slope (Fig 5.3.1f), rugosity (Fig. 5.3.1g), and BPI zones (Fig. 5.3.1h).

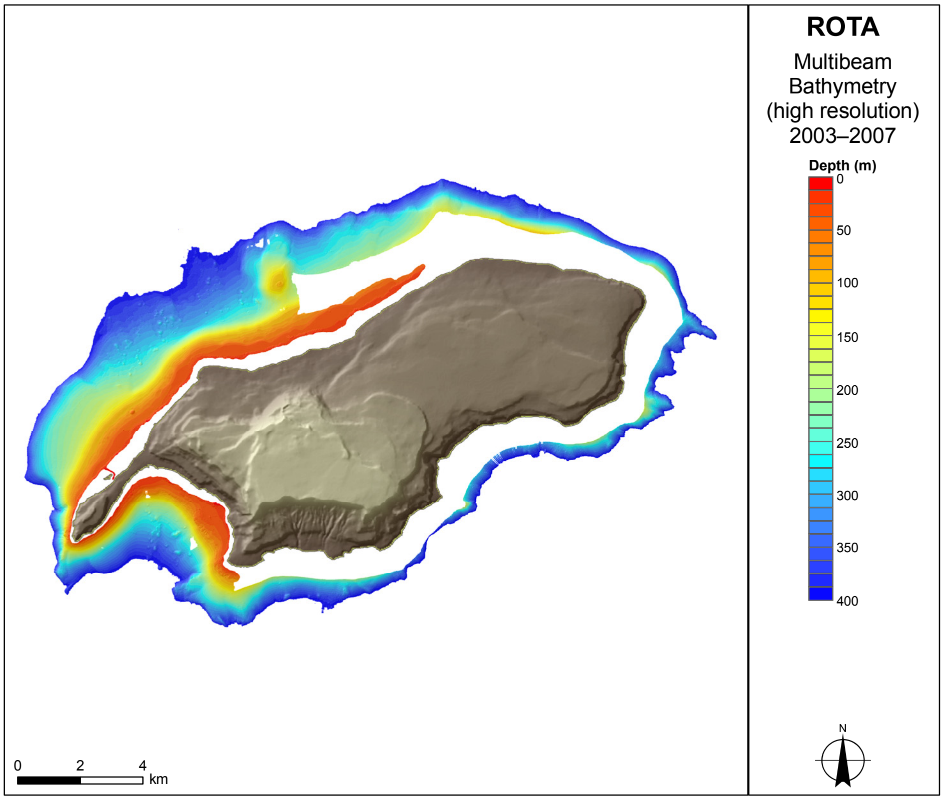



**Figure 5.3.1b.** High-resolution multibeam bathymetry collected around Rota during MARAMP 2003 and 2007. This 5-m bathymetry grid, clipped at 400 m, is used as the basis for slope, rugosity, and BPI derivatives.

The shallowest waters mapped around Rota are characterized by a narrow series of terraces that are likely related to previous sea-levels. The edges of these terraces are most clearly shown in the slope map (Fig. 5.3.1c), which highlights the flat terraces and the steeper slopes of 15°–30° that separate them. Northwest and west of Rota, these terraces are fairly narrow, ~ 600 m at the widest point, and continue to a depth of 100–110 m. Below this series of terraces, a zone of sloping seabed delineated by the BPI analysis (Fig. 5.3.1e) continues to a depth of 200–300 m, which is characterized by slopes < 25°. The seabed below a depth of ~ 300 m is characterized by very low slopes, with the BPI analysis characterizing the area as being composed of a mixture of crests, slopes and flat zones. Large blocks of material, probably resulting from mass wasting, are scattered across the seabed as revealed by all four of the high-resolution bathymetry and derivative maps. Other than around the slopes of these blocks of material, rugosity values across the terraces and on the slopes were generally low.

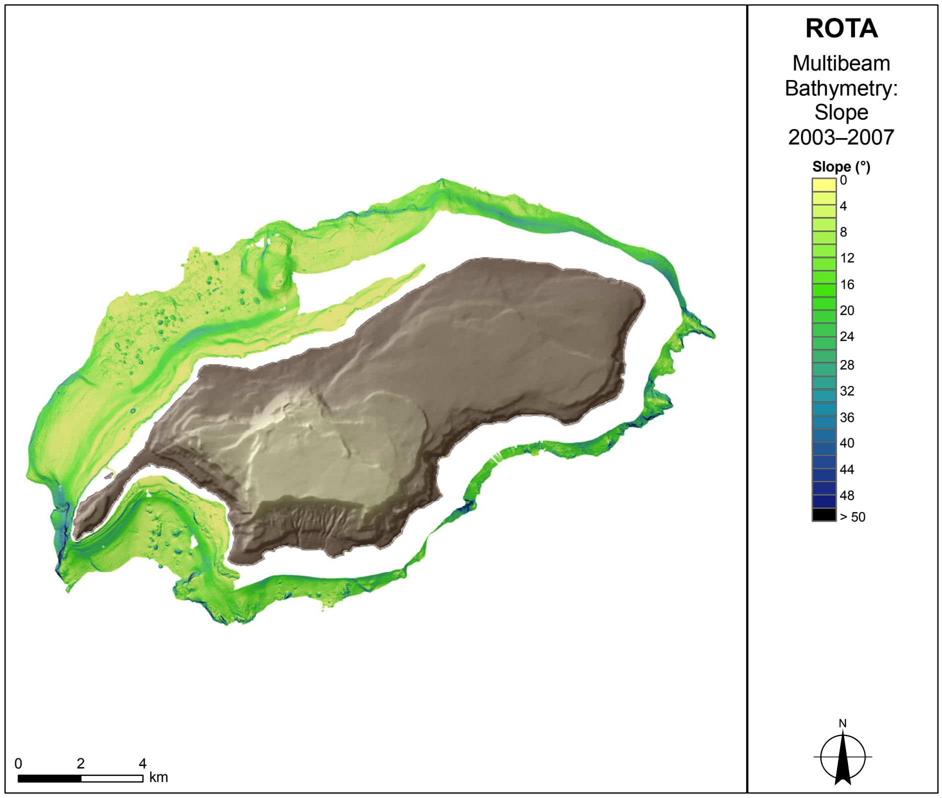



**Figure 5.3.1c.** Slope (°) of 5-m bathymetric grid around Rota. Derived from data collected in 2007, this map reflects the maximum rate of change in elevation between neighboring cells with the steepest slopes shown in the darkest shades of blue and the flattest areas in yellow shades.

In the northwest region, the high-resolution multibeam and slope maps reveal a pinnacle that rises from a depth of ~ 300 m to a depth of 90 m. As with other areas mapped around Rota, the moderately sloping flanks of this pinnacle were characterized by fairly low rugosity levels (Fig. 5.3.1d).

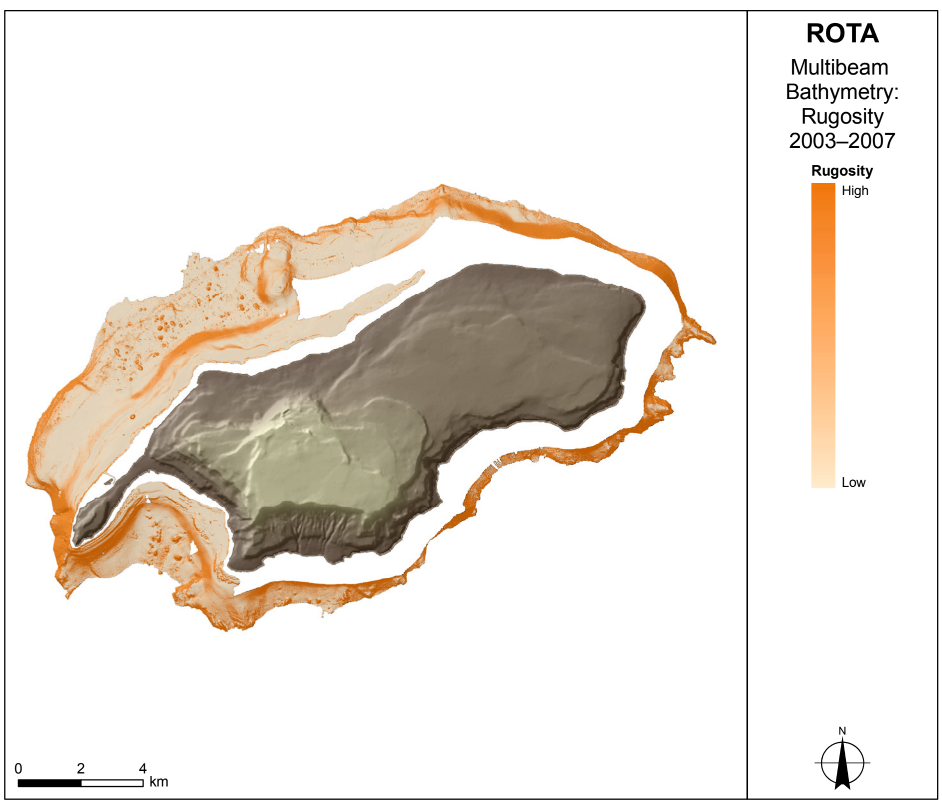



**Figure 5.3.1d.** Rugosity of 5-m bathymetric grid around Rota. Derived from data collected between 2003 and 2007, these rugosity values are a measure of the ratio of surface area to planimetric area within a given cell's neighborhood and indicate topographic roughness.

South of Rota, within Sasanhaya Bay (for place-names and their locations, see Figure 5.2a in Section 5.2: "Survey Effort"), the slope map (Fig. 5.3.1c) highlights the irregular edges of terraced shelves, which are present down to depths of 50–80 m. The slope map also reveals numerous mounds, which may be related to the presence of coral habitats. Below the shelves, the seabed is moderately sloping (< 30°), although the low-rugosity, smooth slopes are punctuated by large blocks of material, often indicative of mass wasting. Southwest of Puntan Pona, the high-resolution data reveal a broad ridge that is a submarine continuation of the coastal feature. The high-resolution multibeam bathymetry and slope map (Figs. 5.3.1b and c) reveal a fairly complex topography with lumpy, closely terraced shelves present down to a depth of ~ 70 m and then another steeply sided ridge below this depth.

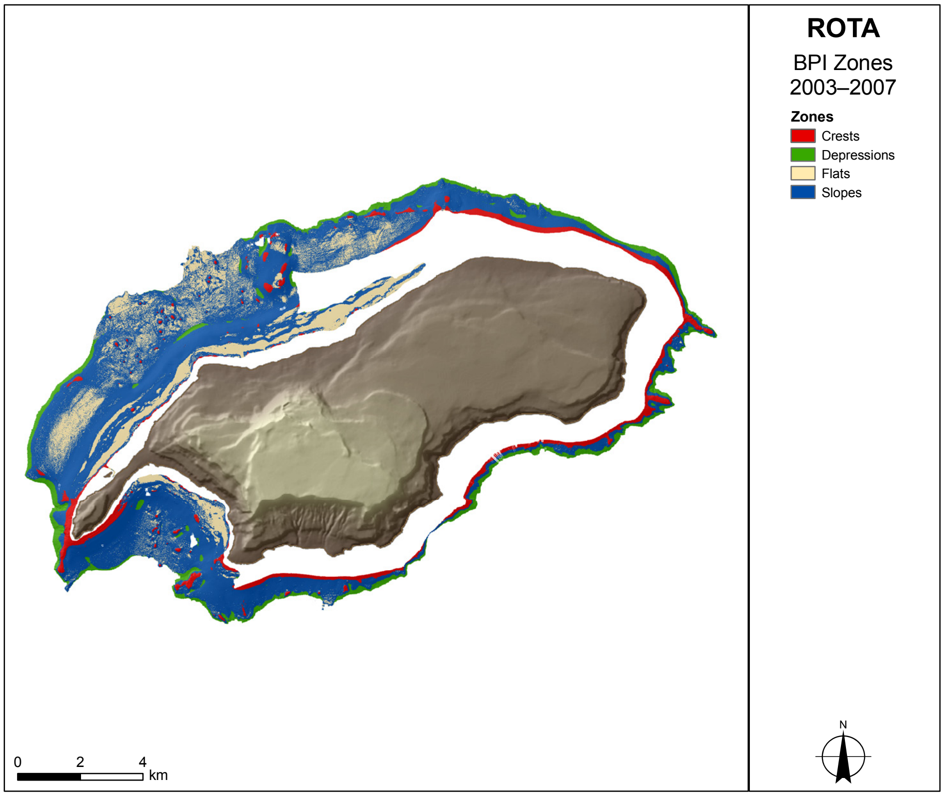
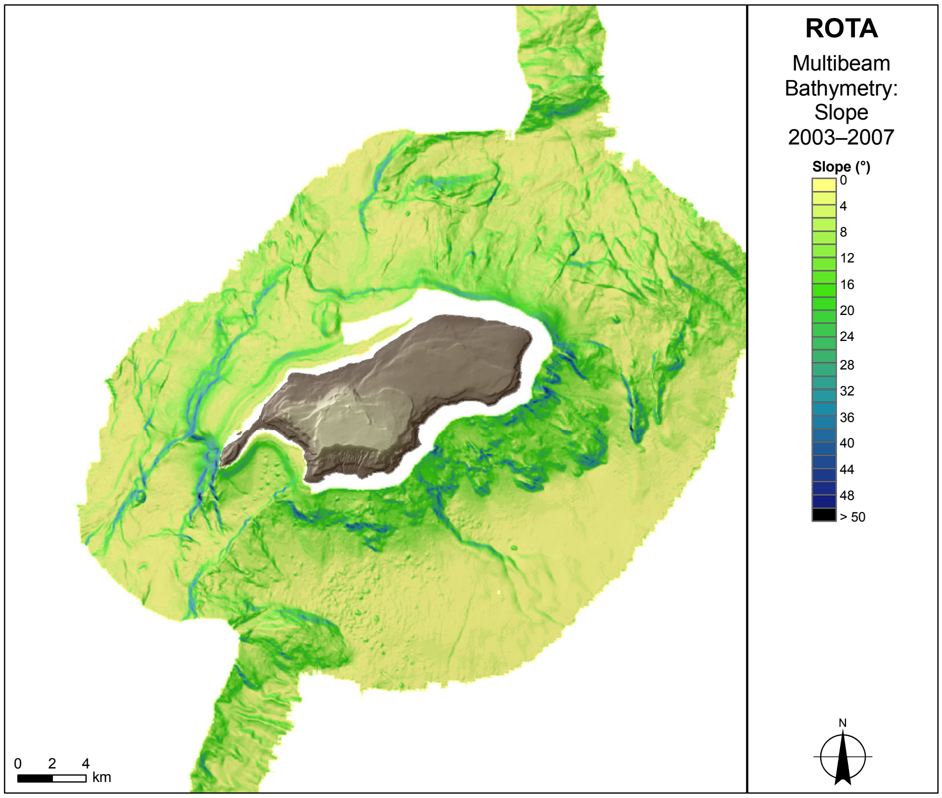



**Figure 5.3.1e.** BPI zones of 5-m bathymetric grid around Rota derived from data collected between 2003 and 2007. BPI is a second-order derivative of bathymetry that evaluates elevation differences between a focal point and the mean elevation of the surrounding cells within a user-defined circle. Four BPI Zones—crests, depressions, flats, and slopes—were used in this analysis.

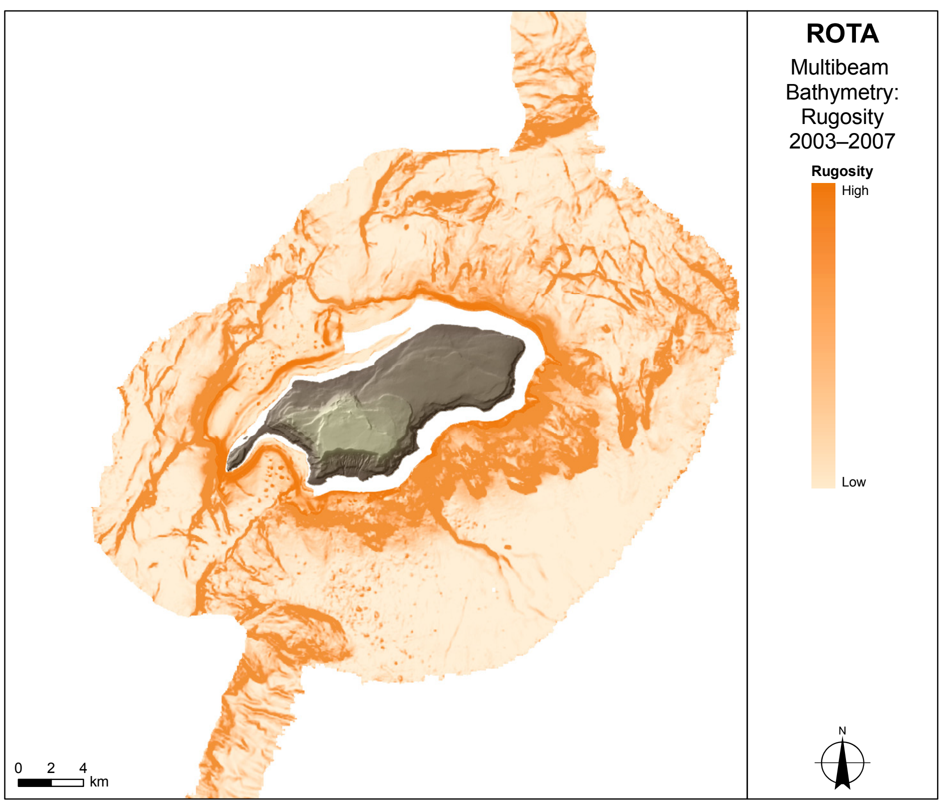
The slope map derived from the low-resolution multibeam bathymetry highlights the markedly different seabed character northwest of Rota versus southeast. North and west of Rota, high slopes of up to 50° were revealed along the edges of the linear scarps (Fig. 5.3.1f) described from the bathymetry data earlier in this section. Aside from these scarp edges, the seabed is relatively flat, with slopes generally < 10°, and characterized by low rugosity (Fig. 5.3.1g). This abundance of flat areas is highlighted in the BPI analysis (Fig. 5.3.1h). In contrast, southeast of Rota, the BPI terrain analysis reveals a distinct region dominated by slopes, crests and depressions with no flat areas. This region is narrowest south of Rota, where it extends to a depth of ~ 1000 m, and widest east of this island where the zone of slopes, crests and depressions continues to ~ 1600 m. Below this region, the seabed was characterized almost entirely as a flat zone, with very low rugosity and slopes recorded.

**Figure 5.3.1f.** Slope (°) of 60-m bathymetric grid around Rota. Derived from data collected in 2007, this map reflects the maximum rate of change in elevation between neighboring cells with the steepest slopes shown in the darkest shades of blue and the flattest areas in yellow shades.




In the shallowest waters surveyed, the BPI analysis identifies reef crests (Fig, 5.3.1h). However, this classification is likely an artifact of the methodology, since no data are available for immediately inshore areas and no comparison can be made to the innermost cells of the grid. Instead, these areas probably should be characterized as slopes.

**Figure 5.3.1g.** Rugosity of 60-m bathymetric grid around Rota. Derived from data collected between 2003 and 2007, these rugosity values are a measure of the ratio of surface area to planimetric area within a given cell's neighborhood and indicate topographic roughness.



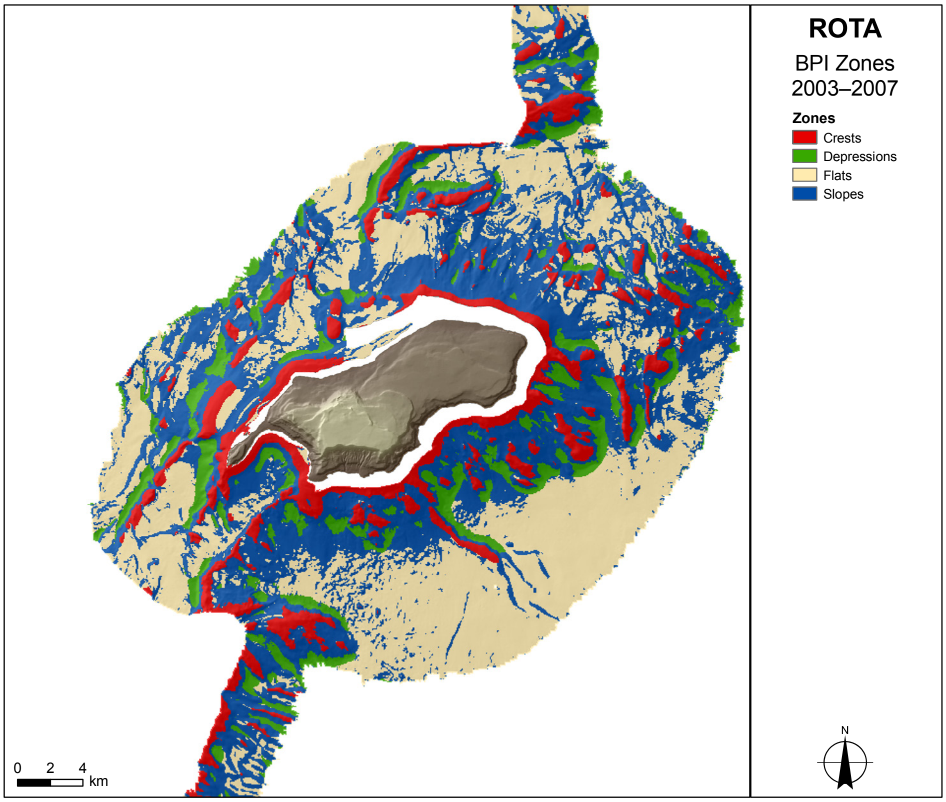



**Figure 5.3.1h.** BPI zones of 60-m bathymetric grid around Rota derived from data collected between 2003 and 2007. BPI is a second-order derivative of bathymetry that evaluates elevation differences between a focal point and the mean elevation of the surrounding cells within a user-defined circle. Four BPI Zones—crests, depressions, flats, and slopes—were used in this analysis.

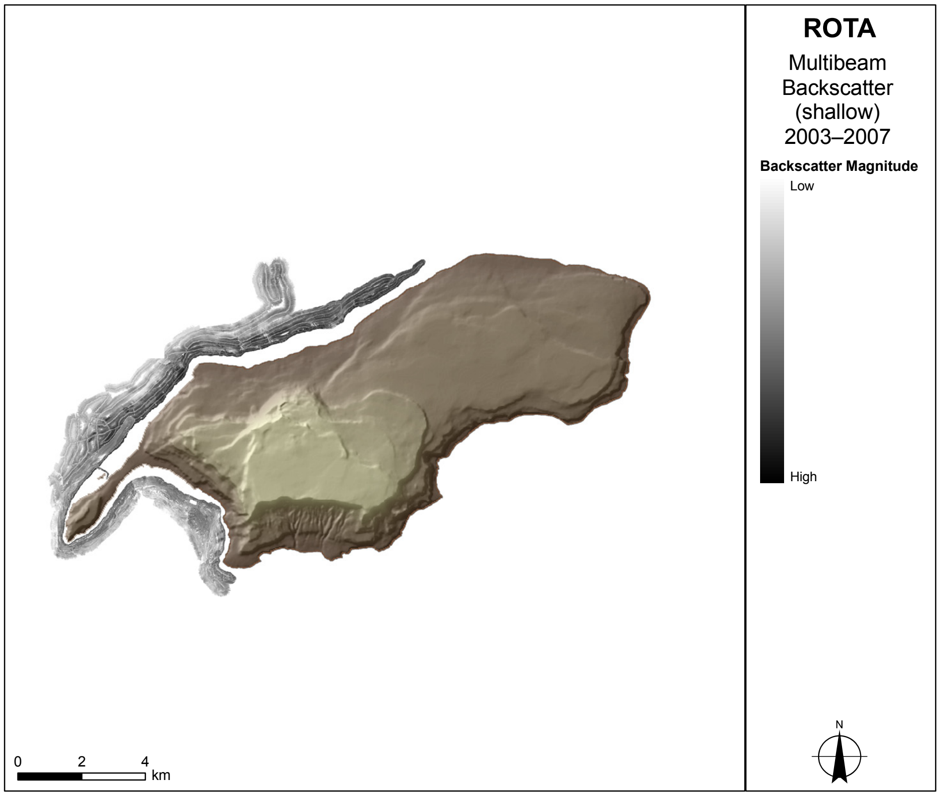
## *High-resolution Multibeam Backscatter and Derivatives*

High-resolution backscatter data were acquired around the western half of Rota using a 240-kHz Reson SeaBat 8101 ER sonar. Because of the limited extent of these data, substrate analysis was not carried out; therefore, no hard–soft substrate map is presented here.

The limited coverage of the shallow backscatter data acquired around Rota makes interpretation somewhat complex. This complexity is further exacerbated by some artifacts present in the data, such as the distinct line at the ship's nadir; in particular west of Rota where crisscrossing tracks make it impossible to see any clear patterns in the backscatter intensity. The area of greatest coverage is south of Rota, within Sasanhaya Bay, and here it is possible to draw some conclusions about the distribution of backscatter values. High-intensity backscatter was recorded along the shelf areas, in particular those characterized by the bumpy topography described from the slope map. These data suggest that these shelves are likely to be characterized by the presence of hard substrates at or near the seabed surface. In contrast, the smoother areas shown on the slope map at greater depths and within the 2 corners of the bay are characterized by lower backscatter values, indicative of softer sediments (Fig. 5.3.1i).

Northwest and west of Rota, the shallow shelves also appear to be characterized by high-intensity backscatter, with lower backscatter values present on the slopes below, but the problems highlighted above make these data more difficult to interpret.

Figure 5.3.1i. Gridded, high-resolution, multibeam backscatter data (grid cell size: 1 m) collected at Rota during MARAMP 2007. Light shades represent low-intensity backscatter and may indicate acoustically absorbent substrates. Dark shades represent high-intensity backscatter and may indicate consolidated hard-bottom and coral substrates.




## 5.3.2 Optical Validation

During MARAMP 2003, 10 TOAD optical-validation surveys were conducted around Rota at depths of 53–188 m. Subsequent analysis of video acquired from these surveys provided estimates of the percentages of sand cover and live-hard-coral cover.

Covering a distance of 71 km at depths of 6–24 m, 33 towed-diver optical-validation surveys of forereef habitats were conducted around Rota during MARAMP 2003, 2005, and 2007. At 5-min intervals within each survey, divers recorded percentages of sand cover and live-hard-coral cover and habitat complexity using a 6-level categorical scale from low to very high.

## 5.3.3 Habitat Characterization

Sand cover, habitat complexity, and live coral cover around Rota are discussed in this section. These descriptions are discussed with reference to the 6 geographic regions around Rota, beginning with the north and east regions and moving clockwise. Towed-diver observations during MARAMP 2003, 2005, and 2007 revealed that the shallow-water habitats around Rota, in general, were characterized by hard substrates supporting fairly low levels of live coral cover. In contrast, TOAD surveys conducted in deeper waters showed habitats characterized by soft substrates with scarce occurrence of live corals.

In the north and east regions, sand cover observed by towed divers was 5.1%–20%, suggesting that these habitats were predominantly characterized by hard substrates (Fig. 5.3.3a). In these regions, towed divers classified the observed habitats as moderate-relief spur-and-groove areas and pavement reef flats of predominantly low to medium-low complexity (Fig. 5.3.3b). These areas also were characterized by having low cover of live corals (interpolated live coral cover < 5%; Fig. 5.3.3c). TOAD surveys of habitats in deeper waters (53–86 m) suggested variable sand cover of 20%–100%, and no live corals were recorded.

Habitats in the southeast region varied in complexity from low to high. These changes in complexity did not occur with changes in the sand cover, which was fairly low (1.1%–20%) throughout this region; however, complexity did relate to variations in live coral cover. Patches of habitats of medium-high to high complexity were associated with moderately

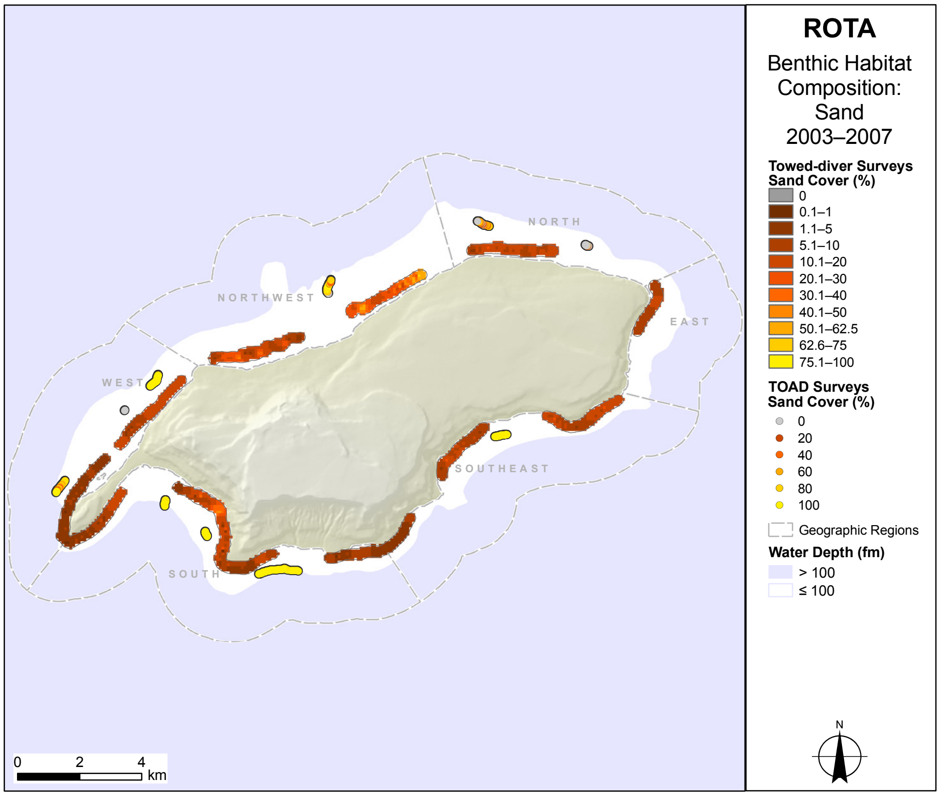



**Figure 5.3.3a.** Observations of sand cover (%) from towed-diver surveys of forereef habitats conducted and analysis of TOAD video collected around Rota during MARAMP 2003, 2005, and 2007.

high live coral cover (5.1%–20%); whereas, elsewhere within this region, cover of live corals was 1.1%–10%. The highest complexity habitats were described by towed divers as high-relief spur-and-groove areas with overhangs, caves, and large boulders. One TOAD survey conducted at depths of 86–100 m suggested substrate of 100% sand cover. No live corals were observed in analyses of video footage from TOAD surveys.

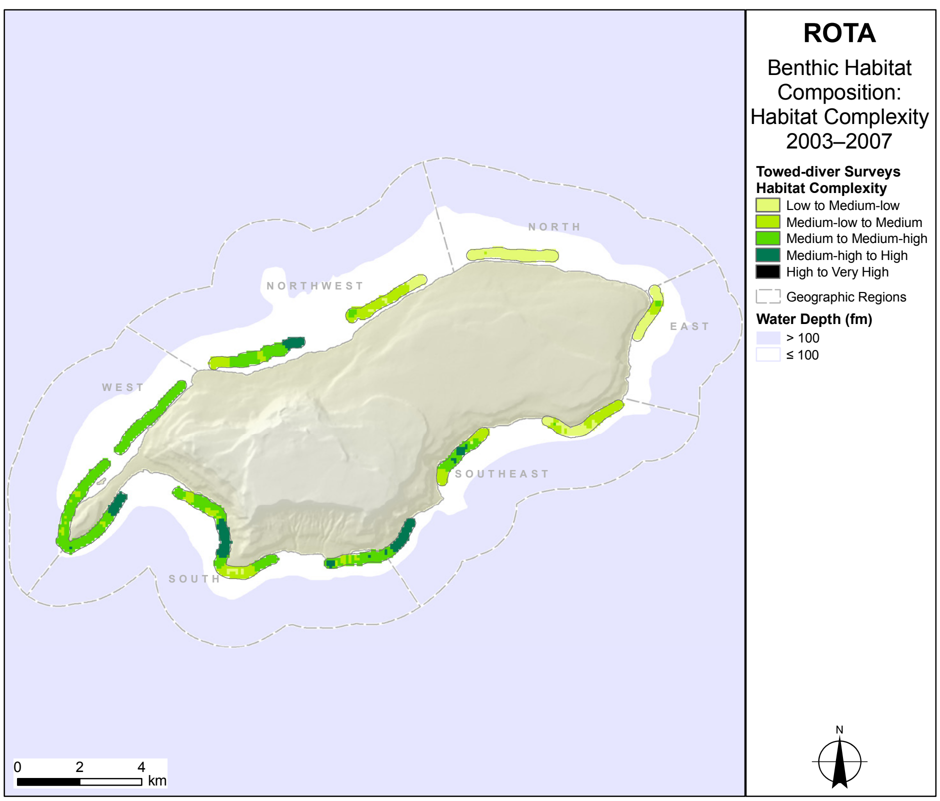



**Figure 5.3.3b.** Observations of benthic habitat complexity from towed-diver surveys of forereef habitats conducted around Rota during MARAMP 2003, 2005, and 2007.

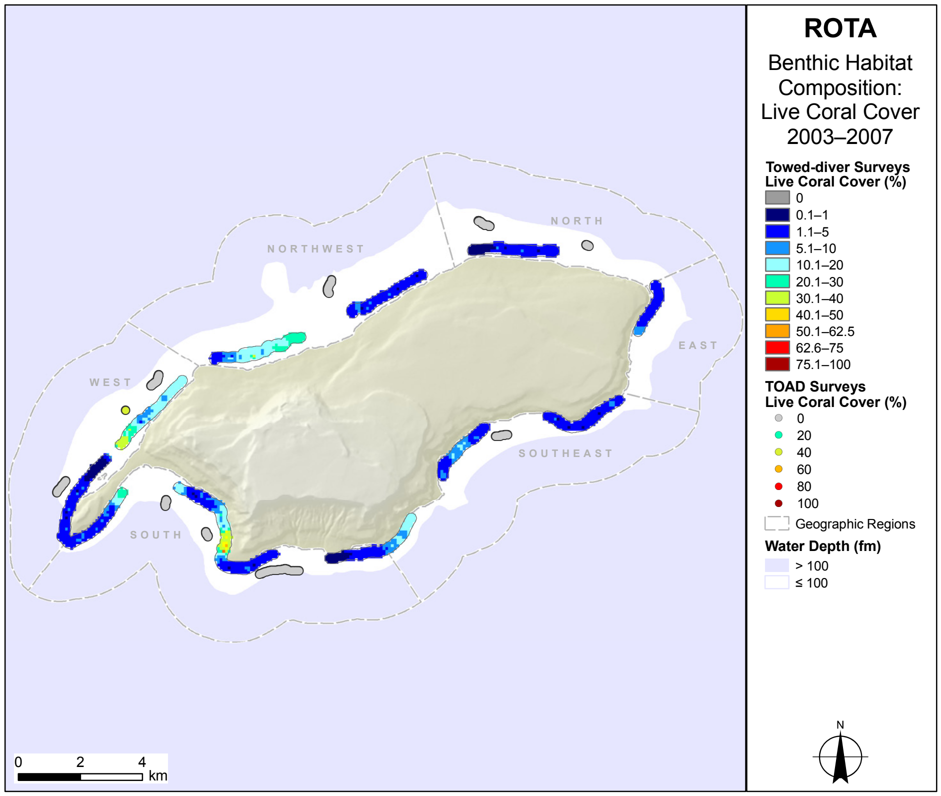



**Figure 5.3.3c.** Cover (%) observations of live hard corals from towed-diver surveys of forereef habitats conducted and analysis of TOAD video collected around Rota during MARAMP 2003, 2005, and 2007.

In the south region, towed divers recorded habitat complexity between medium-low and high. Areas of high-complexity habitat observed within Sasanhaya Bay were associated with the highest levels of live coral cover, with a small patch of cover of 10.1%–20% observed on the west side of the bay and an area of live coral cover of up to 75% recorded on the east side of the bay. This latter area, within Coral Gardens in the Sasanhaya Fish Reserve, had the highest cover of live corals recorded by towed divers around Rota. Elsewhere within the south region, cover of live corals was generally < 20%. Habitats within this region were predominantly characterized by hard substrates, with sand cover mainly < 20%, although interpolated sand cover of up to 50% was recorded within one small patch on the east side of the bay. These hard-substrate habitats were described by towed divers as including pavement reef, boulders, and spur-and-groove habitats, with occasional patch reefs in sand. Three TOAD surveys were conducted at depths or 61–188 m south of Rota. In all 3 surveys, the substrate encountered was 100% sand, with no live corals observed.

In the northwest and west regions of Rota, on either side of Puntan Sailigai, moderately high cover of live corals was observed by towed divers, with interpolated cover within a range of 5.1%–40%. In this same area, habitat complexity ranged from low to high, and observed sand cover was generally 5.1%–20%. In the eastern section of the northwest region, interpolated sand cover of 10.1%–75% was recorded by towed divers. This area had the highest levels of sand observed in any of the shallow waters surveyed by towed divers around Rota. In the adjacent, deeper (83–100 m) waters, TOAD surveys recorded predominantly sandy substrate with sand cover of 20.1%–100%.

Three additional TOAD surveys were conducted in the west region at depths of 70–180 m. One of these surveys was very short, with only 2 video frames analyzed, because the TOAD was too high in the water to allow the habitat characteristics to be classified. Live coral cover of 40% was observed in 1 of these 2 frames. The remaining 2 surveys were longer in duration and were both characterized by predominantly sandy habitats with sand cover of 20.1%–100% and no live corals observed.

## 5.4 Oceanography and Water Quality

### 5.4.1 Hydrographic Data

#### *2003 Spatial Surveys*

During MARAMP 2003, 21 shallow-water conductivity, temperature, and depth (CTD) casts were conducted in nearshore waters around the island of Rota over the period of September 18–20 (Fig. 5.4.1a). Temperature, salinity, and density values from these casts varied both spatially and vertically (Figs. 5.4.1a and b). Spatial comparisons of water properties at a depth of 10 m suggest warm (> 29.95°C) waters around most of this island; however, the west and south regions were generally warmer than all other regions. Salinity and density values showed spatial patterns similar to those seen in temperature values. Levels of both salinity and density generally were lower in the south and west regions than in other regions. The highest density value was recorded at a single location (cast 9) in the north region, and the highest salinity values were recorded at locations in the north and southeast regions (casts 9 and 13). Vertical comparisons of CTD profiles (Fig. 5.4.1b) reveal mostly well-mixed and warm waters around much of this island, except at one location (cast 9) in the north region where differences in values show waters that were much cooler (1.7°C), more saline (0.4 psu), and more dense (0.9 kg m$^{-3}$) than waters at other cast locations. Also, similarly high salinity levels were found at a single location in the southeast region (cast 13).

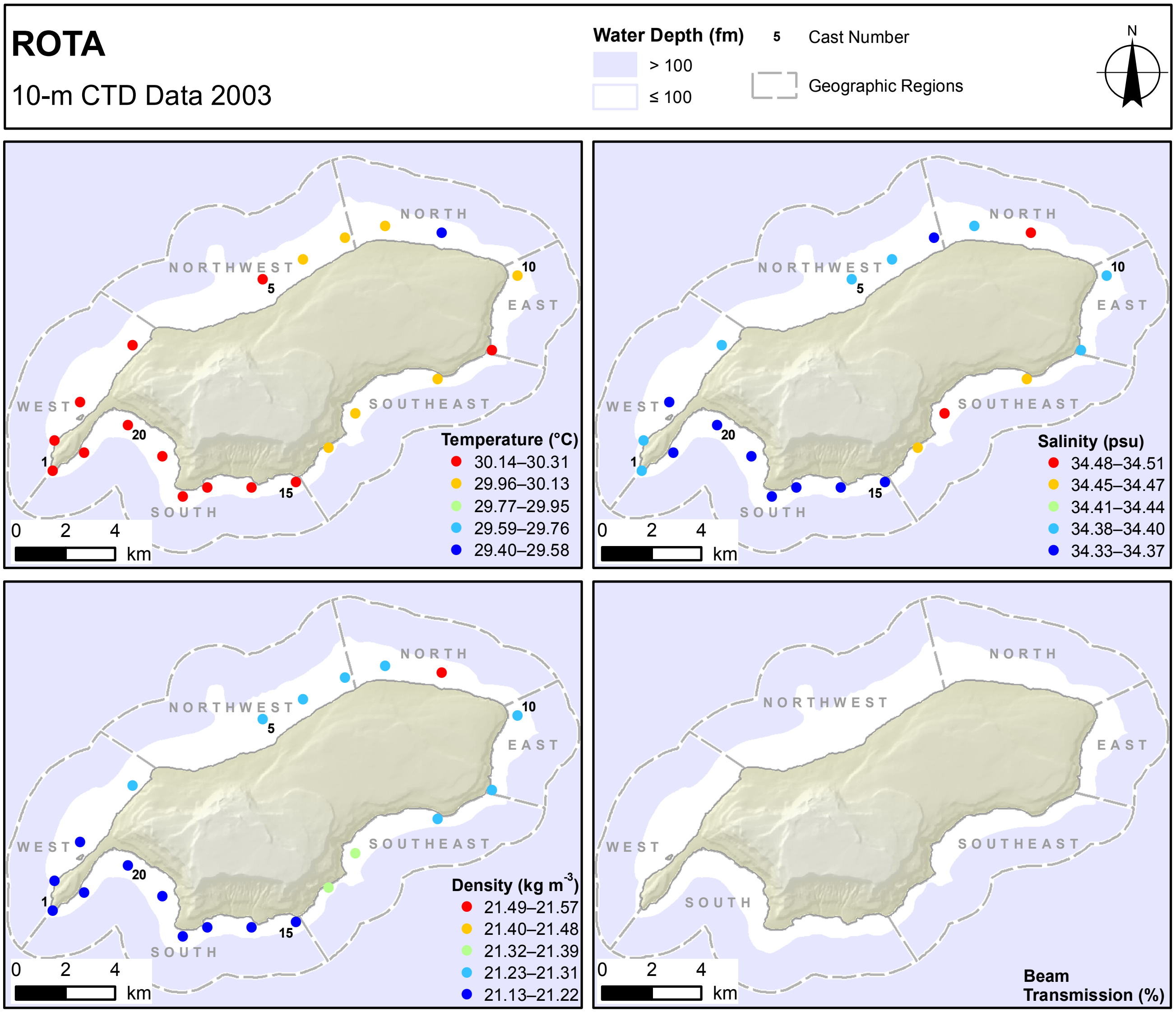
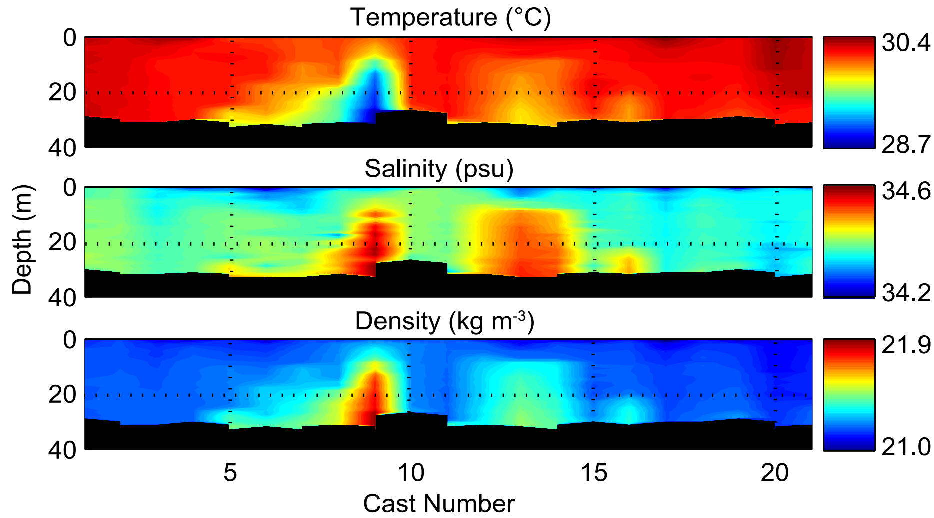



**Figure 5.4.1a.** Values of (*top left*) water temperature, (*top right*) salinity, and (*bottom left*) density at a 10-m depth from shallow-water CTD casts around Rota on September 18–20 during MARAMP 2003.

**Figure 5.4.1b.** Shallow-water CTD cast profiles to a 30-m depth around Rota on September 18–20 during MARAMP 2003, including temperature (°C), salinity (psu), and density (kg m$^{-3}$). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–21 in a clockwise direction around Rota. For cast locations and numbers around this island in 2003, see Figure 5.4.1a.




### *2005 Spatial Surveys*

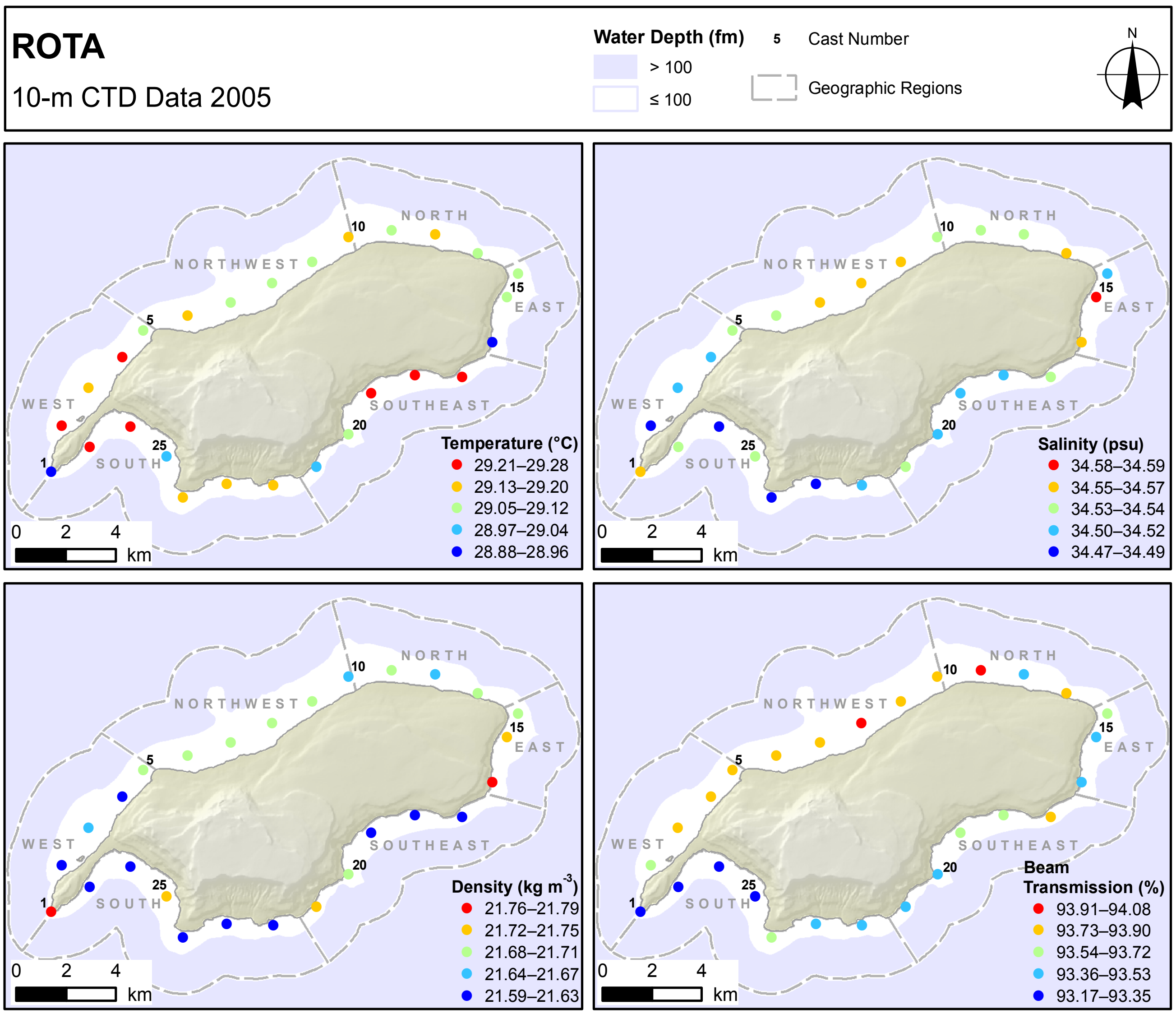



**Figure 5.4.1c.** Values of (*top left*) water temperature, (*top right*) salinity, (*bottom left*) density, and (*bottom right*) beam transmission at a 10-m depth from shallow-water CTD casts around Rota on September 29–October 1 during MARAMP 2005.

During MARAMP 2005, shallow-water CTD casts were conducted in nearshore waters around Rota over the period of September 29–October 1 (Fig. 5.4.1c). Temperature, salinity, density, and beam transmission values from 27 of these casts varied both spatially and vertically (Figs. 5.4.1c and d). Spatial comparisons of water properties at a depth of 10 m suggest slight ranges in all parameters measured. Temperature differences were as large as 0.4°C, although cast locations in the southeast, south, and west regions showed greater heterogeneity compared to the northwest, north, and east regions. Similar variability was seen in recorded density values. Salinity and beam transmission values generally were lower in the southeast, south, and west regions than in the other regions, differences likely associated with subsurface mixing or ground water input. Vertical comparisons of CTD profiles (Fig. 5.4.1d) reveal a complex oceanographic structure around Rota with a broad range in temperature (1.6°C) values, moderate ranges in salinity (0.3 psu) and density (0.5 kg $m^{-3}$) values, and a small range in beam transmission (1.4%) values. A series of intrusions of cold and high-salinity water were recorded in the north and east regions (casts 13 and 16) and to a lesser extent in the south region (casts 23–27). Beam transmission values suggest a less turbid environment in the west, northwest, and north regions (casts 1–15), while, in contrast, the generally lower values recorded along the other half of this island suggest a more turbid environment.

Water samples were collected in concert with shallow-water CTD casts at 4 select locations at Rota in 2005 to assess water-quality conditions. The following ranges of measured parameters were recorded: chlorophyll-*a* (Chl-*a*), 0.15–1.46 µg $L^{-1}$; total nitrogen (TN), 0.181–0.311 µM; nitrate ($NO_3^-$), 0.168–0.284 µM; nitrite ($NO_2^-$), 0.011–0.026 µM; phosphate ($PO_4^{3-}$), 0.002–0.03 µM; and silicate [$Si(OH)_4$], 0.685–0.781 µM. Based on data from these sample locations, nearly all parameters were lower in the west region than in other regions, except for Chl-*a*, which was an order of magnitude greater in concentration than the lowest value recorded at Rota (Fig. 5.4.1e). All nutrient parameters measured, except Chl-*a,* were greatest in the south region.

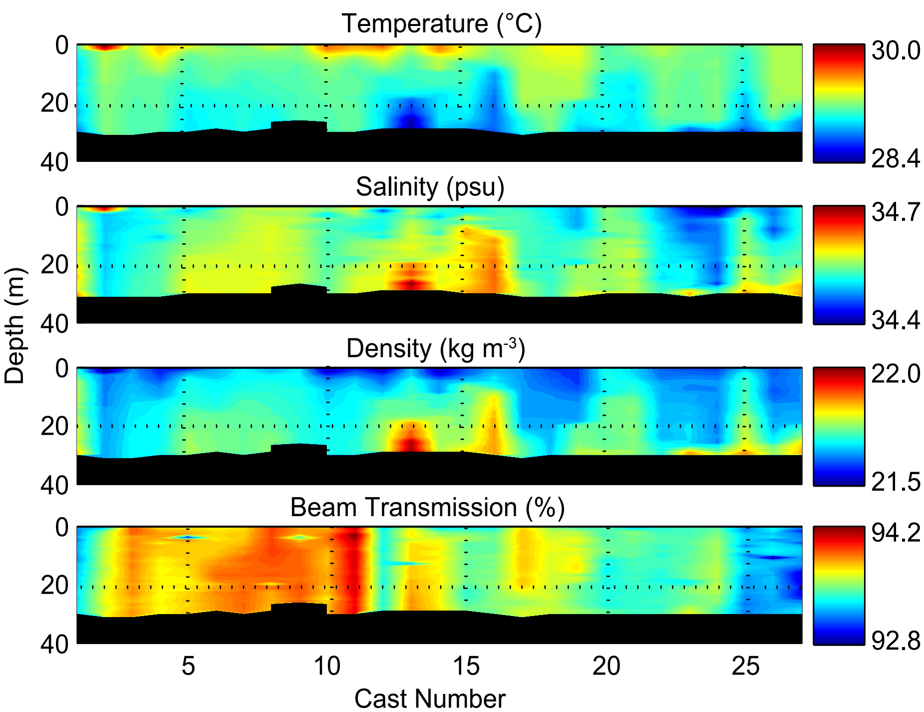



**Figure 5.4.1d.** Shallow-water CTD cast profiles to a 30-m depth around Rota on September 29–October 1 during MARAMP 2005, including temperature (°C), salinity (psu), density (kg $m^{-3}$), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–27 in a clockwise direction around Rota. For cast locations and numbers around this island in 2005, see Figure 5.4.1c.

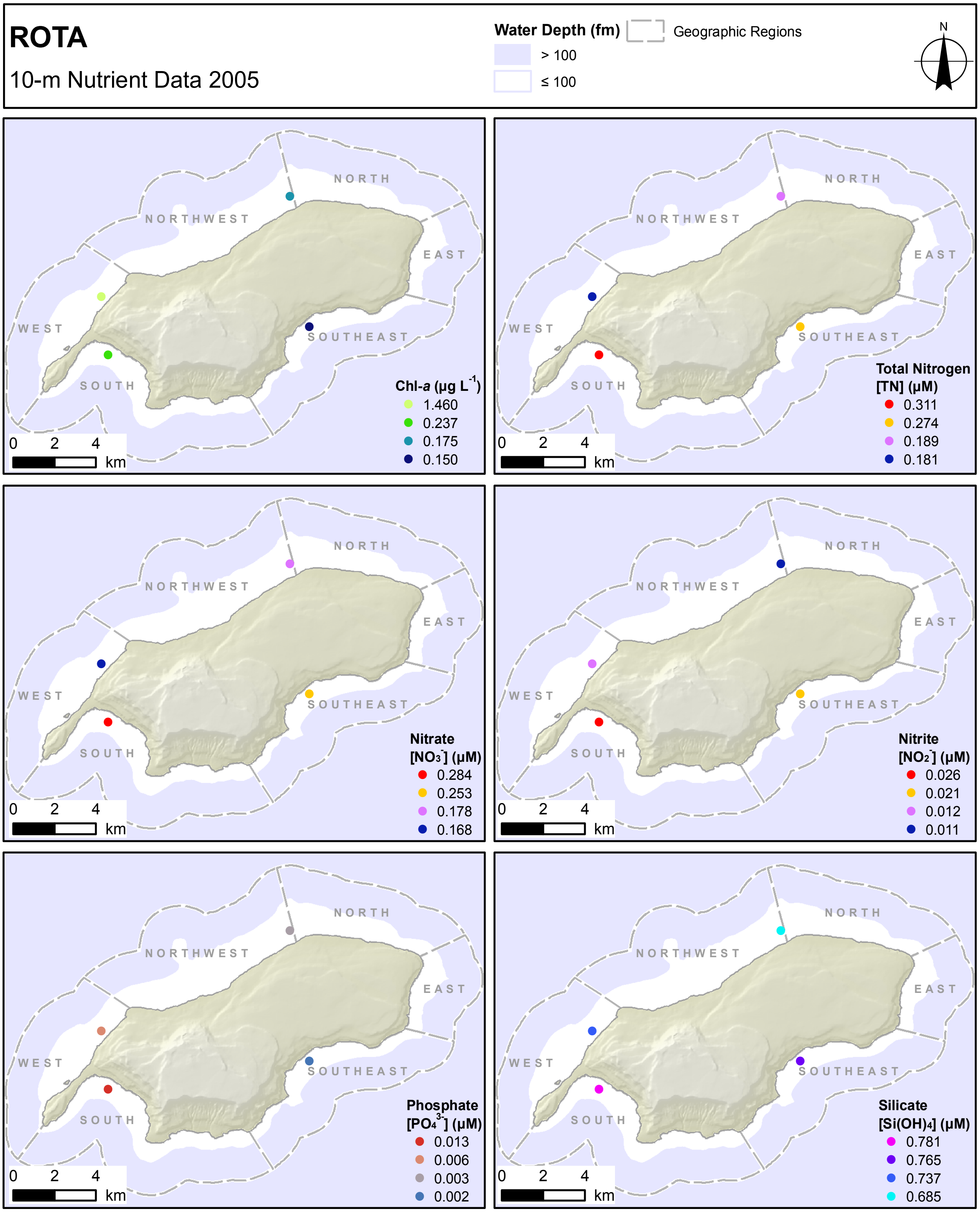



**Figure 5.4.1e.** Concentrations of (*top left*) Chl-*a*, (*top right*) total nitrogen, (*middle left*) nitrate, (*middle right*) nitrite, (*bottom left*) phosphate and (*bottom right*) silicate at a 10-m depth, from water samples collected at Rota on September 29–October 1 during MARAMP 2005.

### *2007 Spatial Surveys*

During MARAMP 2007, shallow-water CTD casts were conducted in nearshore waters around Rota over the period of May 16–17 (Fig. 5.4.1f). Temperature, salinity, density, and beam transmission values from 27 of these casts varied both spatially and vertically (Figs. 5.4.1f and g). Spatial comparisons of water properties at a depth of 10 m suggest small ranges around this island with temperature differences as large as 0.35°C. In general, waters were cooler, more saline, more dense, and less turbid in the west, northwest, and north regions than in the south, southeast, and east regions. Vertical comparisons of CTD profiles (Fig. 5.4.1g) reveal distinct variability around Rota. In the west, northwest, and north regions (casts 1–13) waters from a depth of 30 m to the surface were well mixed and, compared to waters around the rest of this island, were cooler, more dense, and more saline. In the east, southeast, and south regions (casts 14–27) waters were much warmer, less saline, and less dense than in other regions; however, waters at these cast locations exhibited greater stratification and vertical complexity. Beam transmission was generally high around Rota, compared to data collected at other islands, with values around one half of Rota (casts 2–15) slightly higher than around the other half (casts 1 and 16–27).

Water samples were collected in concert with shallow-water CTD casts at 5 select locations around Rota in 2007 to assess water-quality conditions. The following ranges of measured parameters were recorded: Chl-*a*, 0.013–0.135 µg $L^{-1}$; total nitrogen (TN), 0.022–0.185 µM; nitrate ($NO_3^-$), 0.007–0.158 µM; nitrite ($NO_2^-$), 0.016–0.027 µM; phosphate ($PO_4^{3-}$), 0.129–0.154 µM; and silicate [$Si(OH)_4$], 0.721–0.992 µM. Based on data from these sample locations, nearly all parameters were low in the east region and high in the southeast region, compared to results in other regions (Fig. 5.4.1h). In

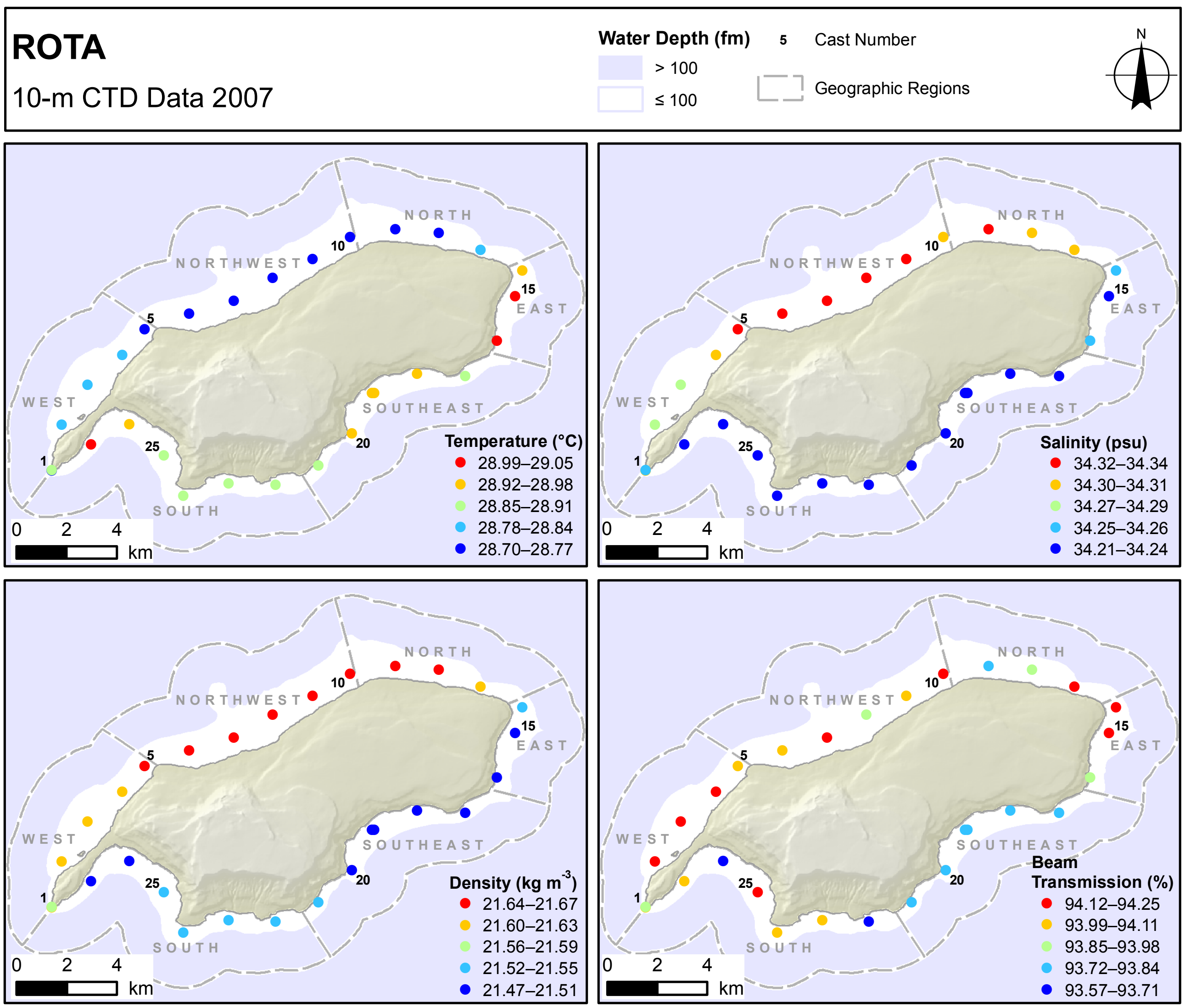



**Figure 5.4.1f.** Values of (*top left*) water temperature, (*top right*) salinity, (*bottom left*) density, and (*bottom right*) beam transmission at a 10-m depth from shallow-water CTD casts around Rota on May 16–17 during MARAMP 2007.

the northwest region, nutrient concentrations were low, but the level of Chl-*a* was an order of magnitude higher than the lowest level found in the east region.

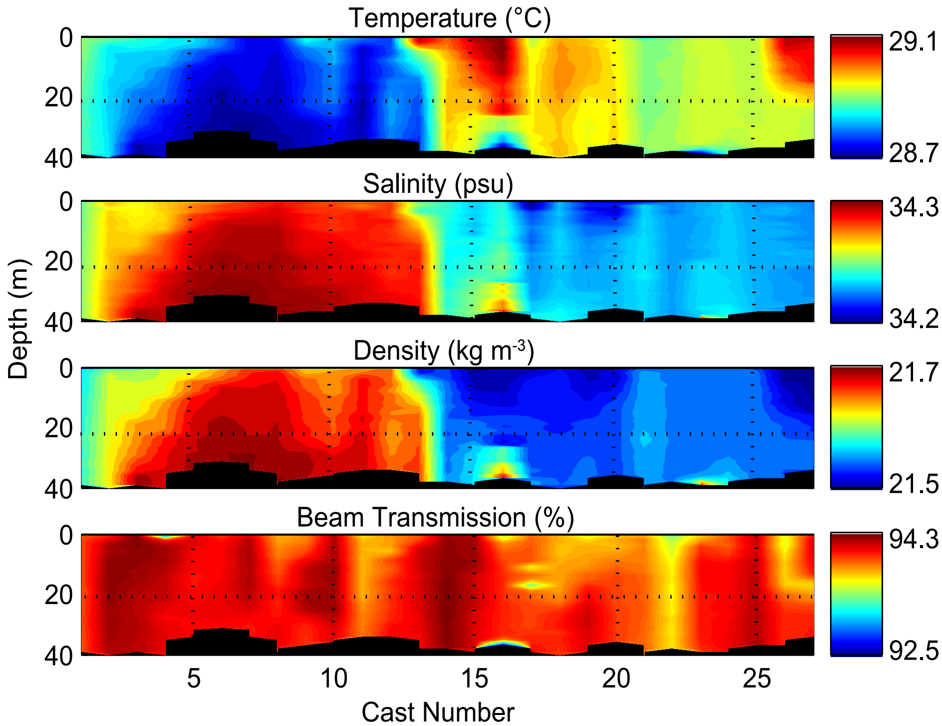



**Figure 5.4.1g.** Shallow-water CTD cast profiles to a 30-m depth around Rota on May 16–17 during MARAMP 2007, including temperature (°C), salinity (psu), density (kg m$^{-3}$), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–27 in a clockwise direction around Rota. For cast locations and numbers around this island in 2007, see Figure 5.4.1f.

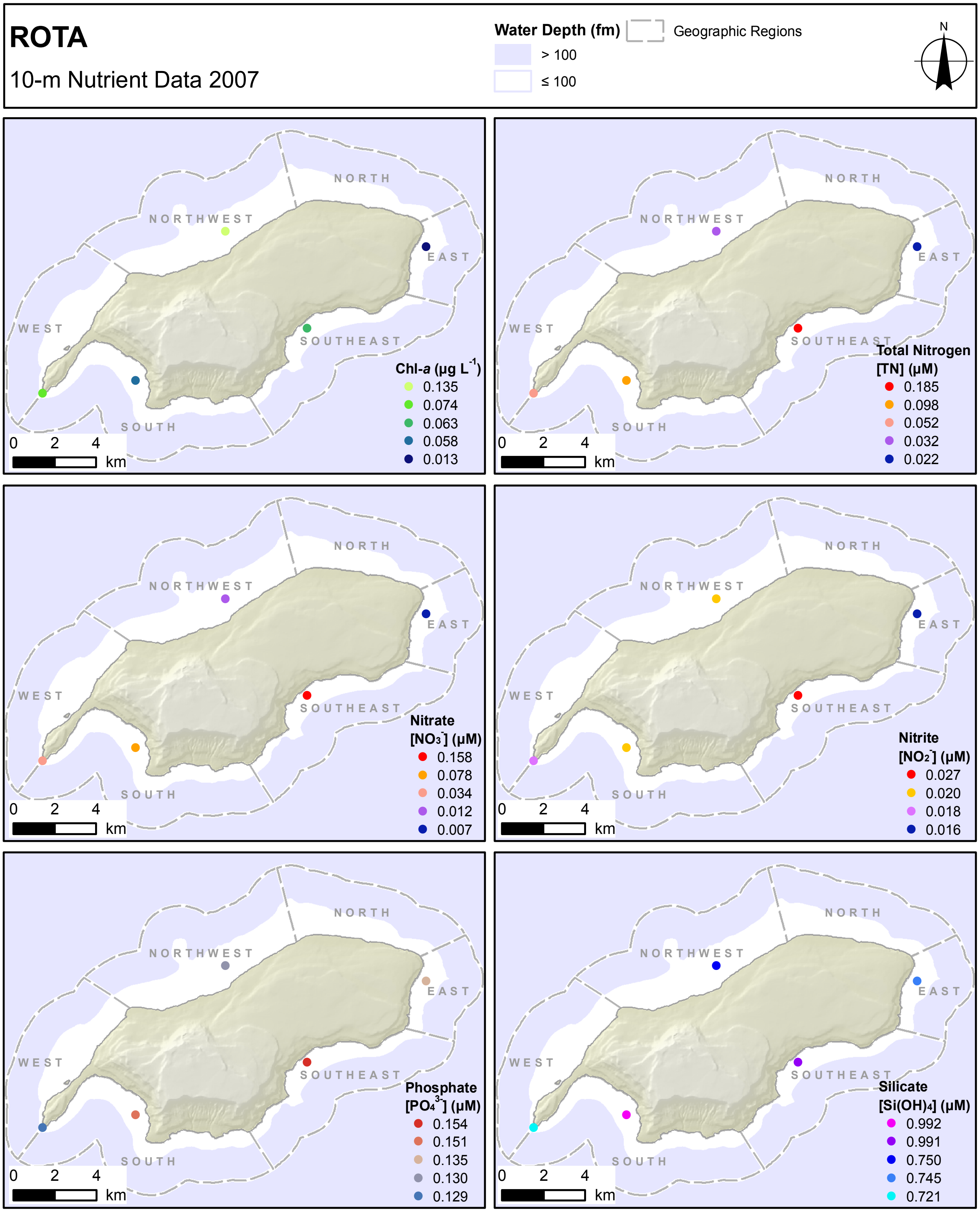



**Figure 5.4.1h.** Concentrations of (*top left*) Chl-*a*, (*top right*) total nitrogen, (*middle left*) nitrate, (*middle right*) nitrite, (*bottom left*) phosphate and (*bottom right*) silicate, at a 10-m depth, from water samples collected at Rota on May 16–17 during MARAMP 2007.

### *Temporal Comparison*

Shallow-water CTD casts conducted during MARAMP 2003, 2005, and 2007 show very different spatial and vertical hydrographic structure around Rota. Intrusions of cold water originating from 30 m below the ocean surface were recorded during MARAMP 2003 and 2005: cold-water intrusions were prevalent at multiple locations in 2005, but waters were mostly well mixed and warm in 2003 with the exception of a single location (cast 9) in the north region. In contrast, a strong east–west gradient in water properties was documented during MARAMP 2007, with waters cooler and more saline along the west- and north-facing shorelines than along the south- and east-facing shores. Beam transmission was high in 2005 and 2007, although a prominent east–west gradient was recorded in 2005 with transmission values higher on the western shorelines than elsewhere around Rota. Data were not collected with respect to a specific tidal cycle, which could be a source of oceanographic variability. Likewise, hydrographic variation between MARAMP survey years is likely a result of differences in season. MARAMP 2007 occurred in May, and MARAMP 2003 and 2005 occurred in September and October. This change was made to avoid the typhoon season and reduce the probability of weather disruptions. Wind and wave conditions are generally higher during the wet season (July–December) than during the rest of the year, with stronger trade winds prominent on the east side of Rota. Higher winds and waves likely caused more mixing during MARAMP 2003 and 2005, and calmer weather potentially allowed for the east–west gradient recorded in 2007. Further investigation will help make these particular results and patterns more apparent.

Some differences in water-quality conditions between MARAMP 2005 and 2007 were observed. Total nitrogen and nitrate concentrations were greater and Chl-*a* levels were an order of magnitude greater in 2005 than in 2007. In contrast, phosphate concentrations were an order of magnitude greater in 2007 than in 2005, and silicate concentrations also were greater. The highest Chl-*a* value was recorded along the northwestern shoreline (north or northwest region) of Rota in both MARAMP survey years, while all nutrient concentrations were greatest along the southern shoreline (south or southeast region). The differences in nitrogen and Chl-*a* concentrations between years could be linked to seasonal weather patterns, terrigenous runoff, or nutrient limitation. Precipitation data show that MARAMP 2005 occurred during a period of seasonally high precipitation, while MARAMP 2007 occurred during a period of seasonally low precipitation (for precipitation information, see Chapter 3: "Archipelagic Comparisons," Section 3.3.1: "Oceanography and Water Quality: Seasonal Climatologies").

## 5.4.2 Time-series Observations

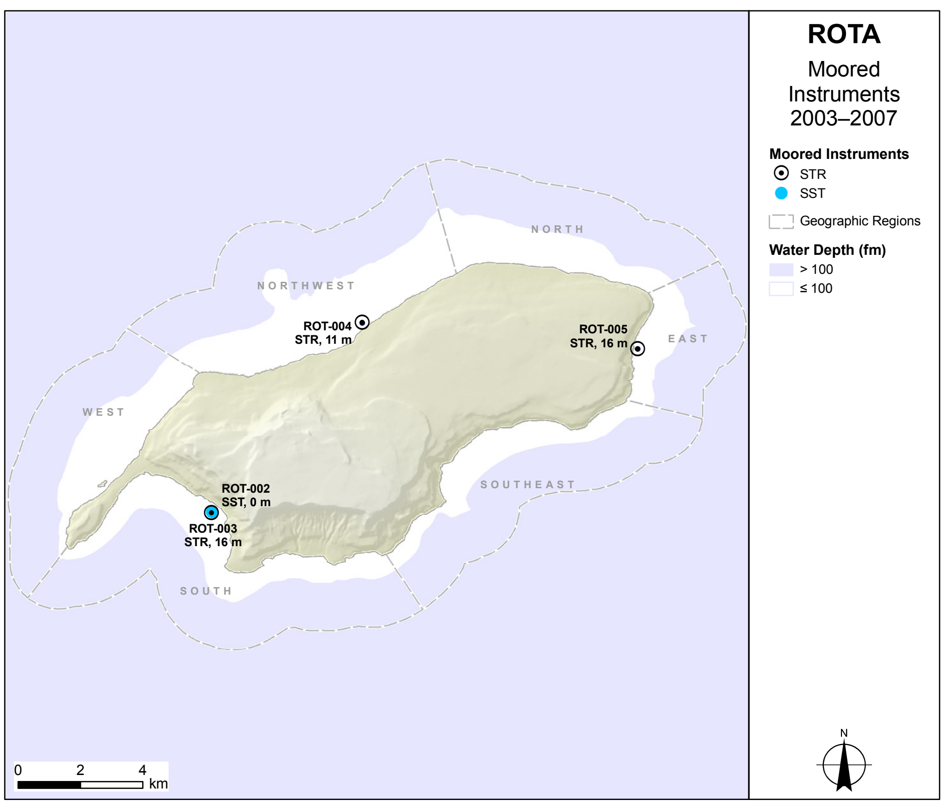



**Figure 5.4.2a.** Locations, depths, and types of oceanographic instrument moorings deployed at Rota during MARAMP 2003, 2005, and 2007. Two types of instruments were moored at Rota: sea-surface temperature (SST) buoy and subsurface temperature recorder (STR).

Between 2003 and 2007, 2 types of moored instruments were deployed at Rota to collect time-series observations of temperature, a key oceanographic parameter. The locations, depths, time frames, and other details about these deployments are provided in Figures 5.4.2a and b.

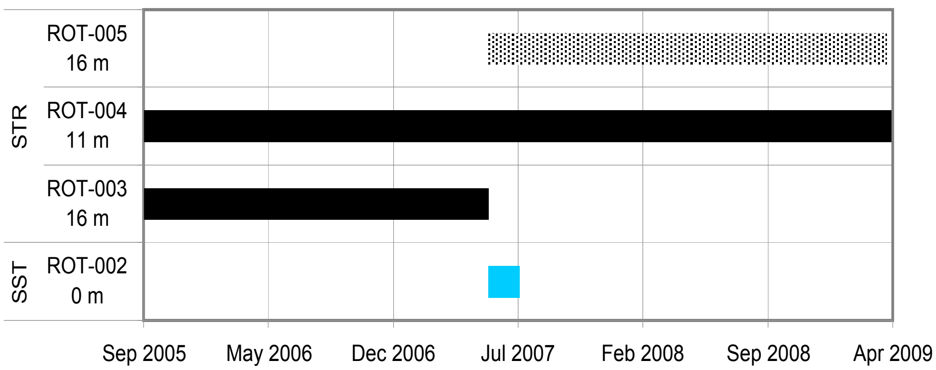



**Figure 5.4.2b.** Deployment timelines and depths of oceanographic instruments moored at Rota during the period from September 2005 to April 2009. A solid bar indicates the period for which temperature data were collected by a single instrument or a series of them deployed and retrieved at a mooring site. A stippled bar indicates that the STR at mooring site ROT-005 and the data it collected were not yet retrieved. The time period shown above for data stored on and collected from an SST buoy may differ from the periods for which telemetered SST data, shown in Figure 5.4.2c, was available.

Satellite-derived (Pathfinder) sea-surface temperature (SST) and in situ temperature observations around Rota reveal that the seasonal maxima for water temperatures around Rota are typically reached in late August or September. The monthly maximum climatological mean from Pathfinder SST was 29.2°C (Fig. 5.4.2c[a]). Winter minima occurred in February with a monthly minimum climatological mean of 27.2°C. Data from the SST buoy deployed in the south region in the Sasanhaya Fish Reserve show that nearshore SST throughout this time series was 0.1°C–1.5°C greater than SST measured via satellite. In situ SST surpassed the bleaching threshold, which is defined as 1°C above the monthly maximum climatological mean, multiple times during the summer months of 2003–2006, with a particularly warm episode of 1.2°C above the bleaching threshold recorded in September 2006. Recorded at a location highly sheltered from prevailing trade winds and associated swell, the high SST values measured via this SST buoy are not an accurate representation of temperatures from around this entire island. However, these data are accurate for this location and show the importance of prevailing oceanographic phenomena for nearshore thermal dynamics. It's important to note that satellite-derived SST represents the upper few millimeters of oceanographic temperatures within the region of an island, as opposed to site- or reef-specific temperatures.

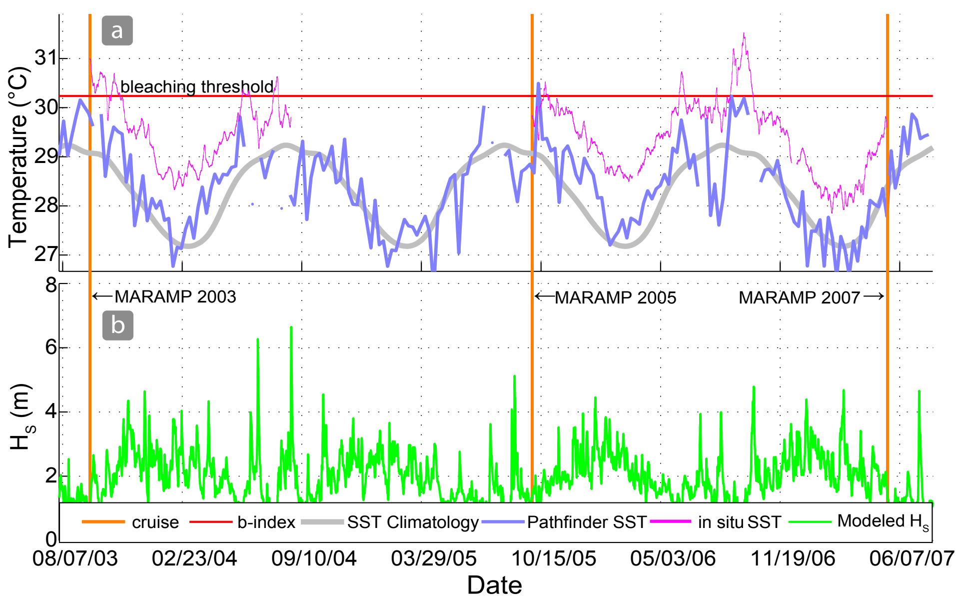



**Figure 5.4.2c.** Time-series observations of (*a*) SST and (*b*) wave height around Rota for the period between August 2003 and June 2007. Remotely sensed data (SST climatology and weekly Pathfinder-derived SST) and modeled significant wave height (Hs) derived from Wave Watch III are shown with CRED in situ temperature data from SST buoys (see Figure 5.4.2a for buoy location). The 2 high points in the modeled wave height in the summer of 2004 show the occurrences of Typhoons Tingting and Chaba. The horizontal red and vertical orange bars represent the bleaching threshold and the MARAMP research cruise dates, respectively.

Periods of elevated mean wave heights of 3–4 m were usually more frequent during winter (Fig. 5.4.2c[b]). The largest episodic events of wave heights > 4 m, however, tended to happen during periods of warm temperatures. Warm temperatures typically occurred during the period of August–December when wave heights > 4 m were generally associated with typhoons. This pattern was especially noticeable during the summer of 2004 with the passages of Typhoons Tingting and Chaba.

Subsurface temperature recorders (STRs) were deployed at 2 locations at depths of 11 and 16 m in the south and northwest regions of Rota beginning in October 2005. Data from these STRs show seasonal temperature variability of 2°C–3°C (Fig. 5.4.2d). Water temperatures reached ~ 30.5°C during the months of June–October and fell to a low of ~ 27.5°C during the months of January–May. Temperature at these 2 locations reached the coral bleaching threshold for the region in September 2006, with the temperature at the shallower sensor reaching 0.5°C higher than the bleaching threshold of 30.5°C. Both STRs showed high-frequency (return periods of 12–24 h) temperature fluctuations of 0.5°C–1°C that were likely associated with the vertical uplift of a stratified water column.

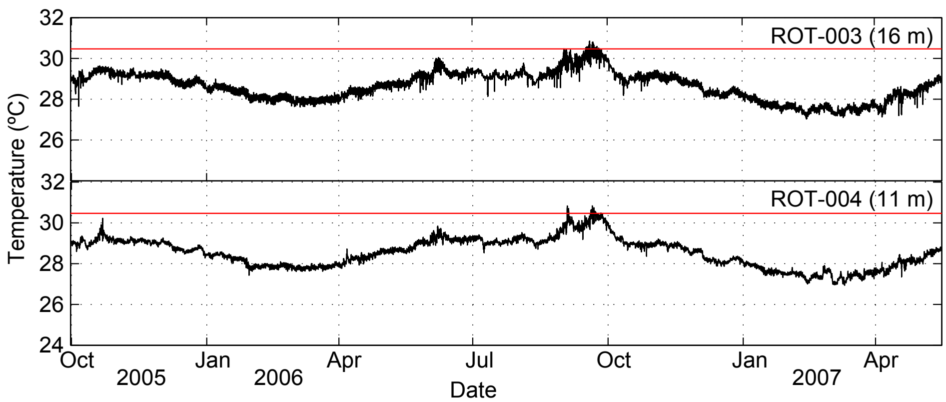



**Figure 5.4.2d.** Time-series observations of temperature over the period between October 2005 and May 2007 collected from 2 STR mooring sites at different locations and depths at Rota (see Figure 5.4.2a for mooring locations). The red lines indicate the satellite-derived coral bleaching threshold, which is defined as 1°C above the monthly maximum climatological mean.

### 5.4.3 Wave Watch III Climatology

Seasonal wave climatology for Rota was derived using the NOAA Wave Watch III model for the period of January 1997 to May 2008 (Fig. 5.4.3a), and seasons were selected to elucidate waves generated by typhoons, which most frequently occur during the period of August–December (for information about the Wave Watch III model, see Chapter 2: “Methods and Operational Background,” Section 2.3.7: “Satellite Remote Sensing and Ocean Modeling”). In terms of consistency, the wave regime during this period was dominated by trade wind swells characterized by frequent (> 30 d per season), short-period (8–10 s), relatively small (2–3 m) wave events originating from the east (~ 70°). Superimposed with these short-period swells were large (> 4 m), long-period (12–16 s) wave events principally from the east-southeast (120°), although they could originate from a broad directional source (110°–200°). These large, episodic waves primarily were generated via typhoons and occurred on annual to interannual time scales. Additionally, infrequent (~ 5 d per season), long-period (12–14 s) swells with moderate wave heights (2.5–3.5 m) occurred from the west and southwest (240°–270°) and probably were associated with episodic storms. Similar to the wave regime during typhoon season, the wave climate during the period of February–June (outside the typhoon season) was also characterized by frequent (> 30 d per season), short-period (~ 8 s) trade wind swells with relatively small wave heights (~ 2 m) originating from the east. Infrequent (< 5 d per season), long-period (12–14 s) swells with slightly larger wave heights (~ 3 m) also occurred during this time and originated from the southwest (~ 240°).

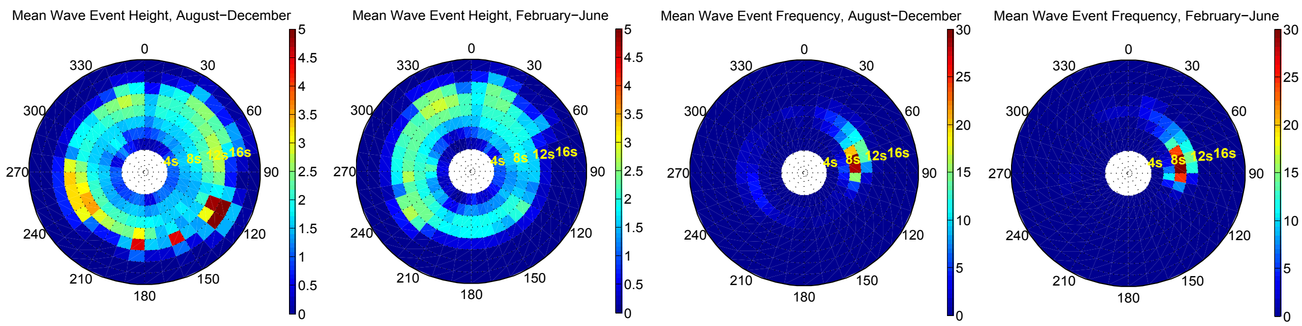



**Figure 5.4.3a.** NOAA Wave Watch III directional wave climatology for Rota from January 1997 to May 2008. This climatology was created by binning (6 times daily) significant wave height, dominant period, and dominant direction from a box (1° × 1°) centered on Rota (13° N, 145° E). Mean significant wave height (*far left and left*), indicated by color scale, for all observations in each directional and frequency bin from August to December (typhoon season) and from February to June. The transition months of January and July are omitted for clarity. Mean number of days (*right and far right*) that conditions in each directional and frequency bin occurred in each season, indicated by color scale; for example, if the color indicates 30, then, on average, the condition occurred during 30 out of 150 days of that season.

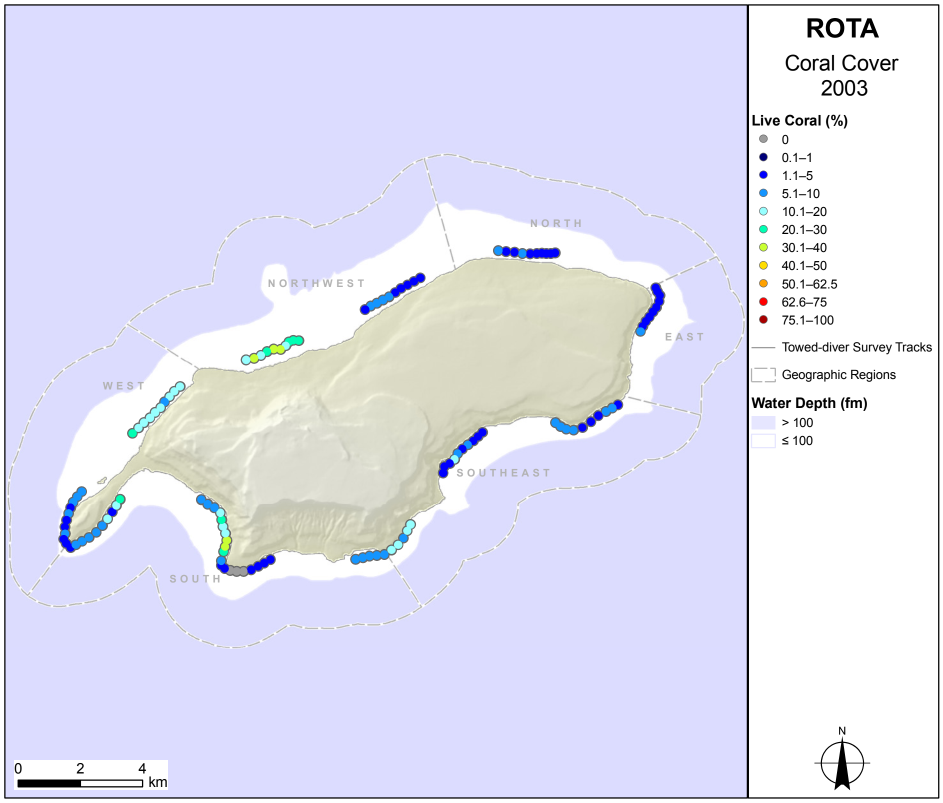
## 5.5 Corals and Coral Disease

### 5.5.1 Coral Surveys

#### *Coral Cover and Density*

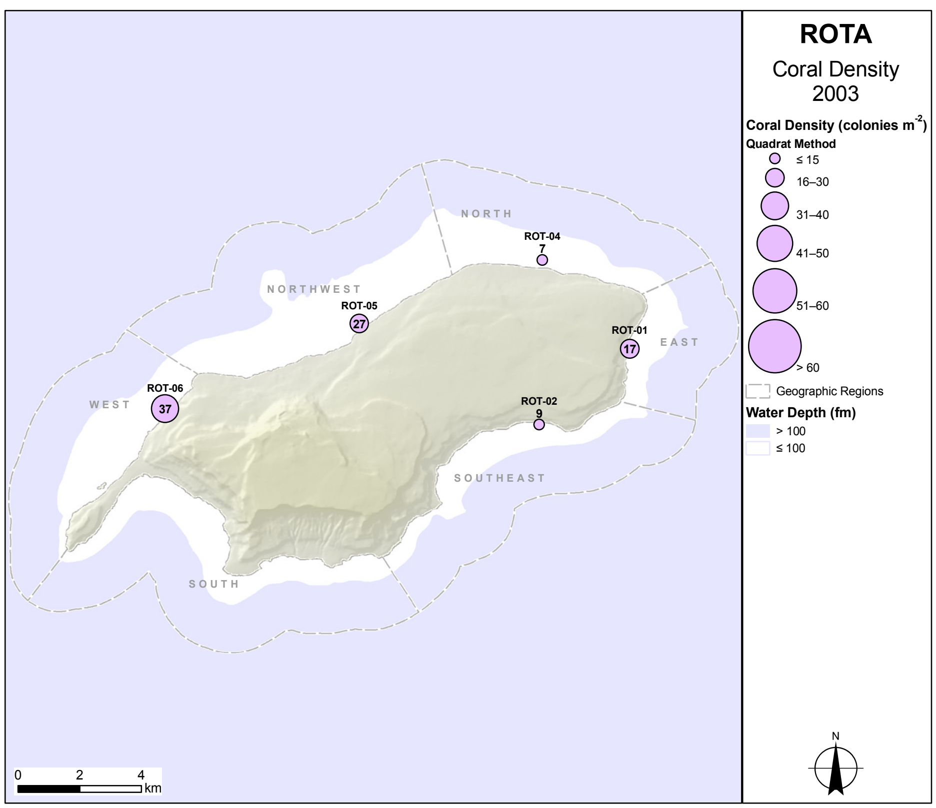
From MARAMP 2003 towed-diver surveys, mean cover of live hard corals on forereef habitats around the island of Rota was 9% (SE 1). Coral cover was lowest over the 5 surveys conducted around the eastern half of Rota, with < 10% coral cover recorded for 49 of 50 survey segments (Fig. 5.5.1a): the easternmost survey in the northwest region, the survey near Asuzudo and Mochon Points in the north region, the survey near Puntan Fina`atkos in the east region, and the 2 surveys nearest to Puntan Sagua`gahga in the southeast region (for place-names and their locations, see Figure 5.2a in Section 5.2: “Survey Effort”). Coral cover was highest for the survey conducted just east of Puntan Sailigai in the northwest region with a mean of 25% for 10 segments. Localized areas of high coral cover were also found in the south region in Coral Gardens, which is in the Sasanhaya Fish Reserve, with a mean of 24% over 7 segments.

**Figure 5.5.1a.** Cover (%) observations of live hard corals from towed-diver benthic surveys of forereef habitats conducted around Rota during MARAMP 2003. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of ~ 200 x 10 m (~ 2000 m²).




During MARAMP 2003, 5 REA benthic surveys using the quadrat method on forereef habitats at Rota documented 364 coral colonies within a total survey area of 18.75 m$^2$. Site-specific colony densities ranged from 6.9 to 37.1 colonies m$^{-2}$ with an overall sample mean of 19.4 colonies m$^{-2}$ (SE 5.7). The highest colony density was observed in the west region at REA site ROT-06 southwest of Puntan Sailigai, and the lowest colony density was recorded in the north region at ROT-04 near Mochon Point (Fig. 5.5.1b).

**Figure 5.5.1b.** Colony-density (colonies m$^{-2}$) observations of live hard corals from REA benthic surveys of forereef habitats conducted at Rota during MARAMP 2003. Values are provided within or above each symbol. The quadrat method was used in 2003 to assess coral-colony density.



From MARAMP 2005 towed-diver surveys, mean cover of live hard corals on forereef habitats at Rota was 6% (SE 1). Coral cover was < 10% in the majority (87%) of the 108 segments surveyed at Rota. Coral cover was highest in the south region in Coral Gardens with a mean of 49% over 3 segments (Fig. 5.5.1c). A localized area of high coral cover, relative to other areas surveyed at Rota, was also found in the west region near Sasanlagu (West) Harbor, where cover was estimated at 29% over 5 segments.

Towed divers during MARAMP 2005 recorded estimates of stressed-coral cover, including corals that were fully bleached (white), pale or discolored, malformed, or stricken with tumors (see Chapter 2: "Methods and Operational Background," Section 2.4.5, "Corals and Coral Disease"). Overall, 2% (SE 1) of coral cover observed on forereef habitats at Rota appeared stressed in 2005. Low values of stressed-coral cover were seen during the majority of segments. Stressed-coral cover was highest, within a range of 40.1%–50% for 2 segments and a range of 10.1%–20% for a third segment, in the southeast region near Puntan Sagua`gahga (Fig. 5.5.1c). An additional area of stressed-coral cover, within a range of 10.1%–20% for 3 segments, was observed in the northwest region near Puntan Sailigai.

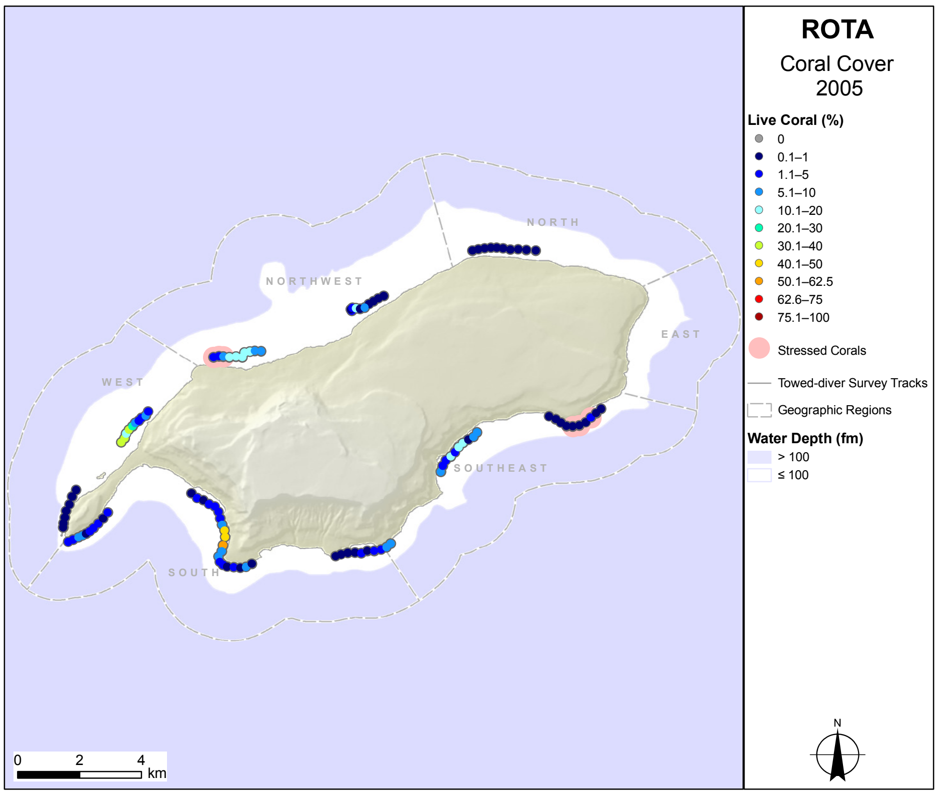



**Figure 5.5.1c.** Cover (%) observations of live and stressed hard corals from towed-diver benthic surveys of forereef habitats conducted at Rota during MARAMP 2005. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of ~ 200 x 10 m (~ 2000 m²). Pink symbols represent segments where estimates of stressed-coral cover were > 10%. Stressed-coral cover was measured as a percentage of overall coral cover in 2005.

During MARAMP 2005, 5 REA benthic surveys using the quadrat method on forereef habitats at Rota documented 599 coral colonies within a total survey area of 20 $m^2$. Site-specific colony densities ranged from 9.5 to 52.4 colonies $m^{-2}$ with an overall sample mean of 30 colonies $m^{-2}$ (SE 8.1). Similar to results from MARAMP 2003 surveys, the highest colony density was observed at ROT-06 in the west region (Fig. 5.5.1d). ROT-04, where the lowest colony density was found in 2003, was not surveyed in 2005; however, the lowest colony density in 2005 was recorded in the southeast region at ROT-02, the REA site with the second-lowest colony density in 2003.

From MARAMP 2007 towed-diver surveys, mean cover of live hard corals on forereef habitats at Rota was 4% (SE 1). Coral cover was < 10% in the majority (93%) of the 100 segments surveyed at Rota (Fig. 5.5.1e). Coral cover was highest in the south region in Coral Gardens with a mean of 58% over 3 segments.

Overall, 1% (SE 0) of coral cover observed on forereef habitats at Rota appeared stressed in 2007. Low values of stressed-coral cover were observed during the majority of segments (Fig. 5.5.1e). Stressed-coral cover was highest, within a range of 10.1%–20%, for 1 segment in the southeast region midway between Puntans Sagua`gahga and Ha`ina.

**Figure 5.5.1d.** Colony-density (colonies m$^{-2}$) observations of live hard corals from REA benthic surveys of forereef habitats conducted at Rota during MARAMP 2005. Values are provided within or above each symbol. The quadrat method was used in 2005 to assess coral-colony density.

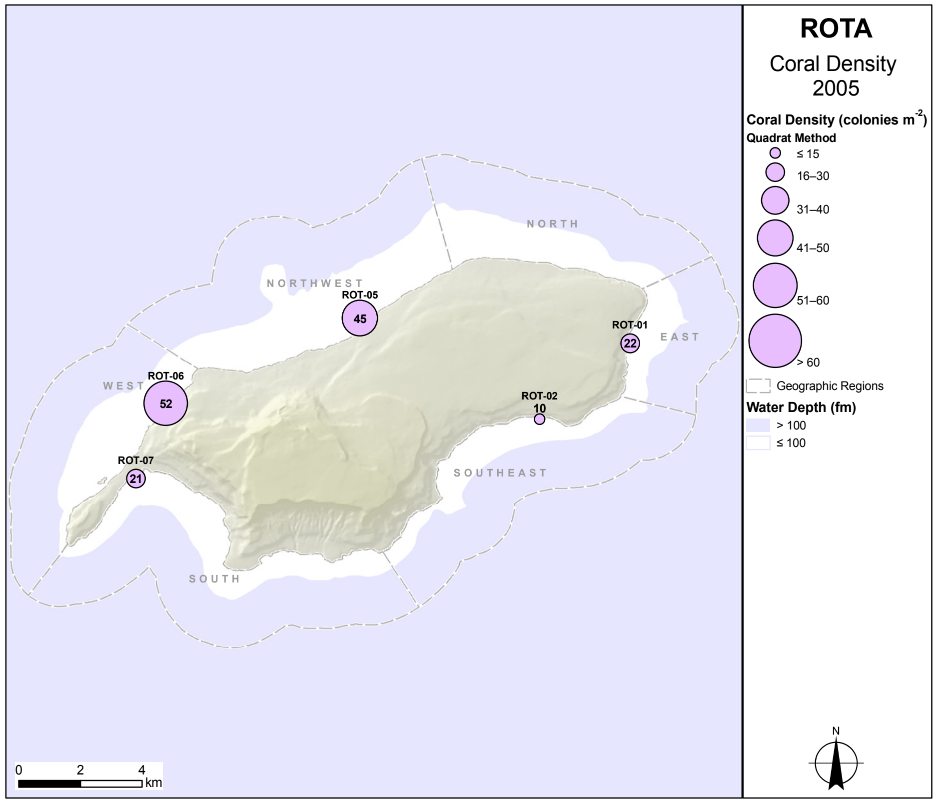
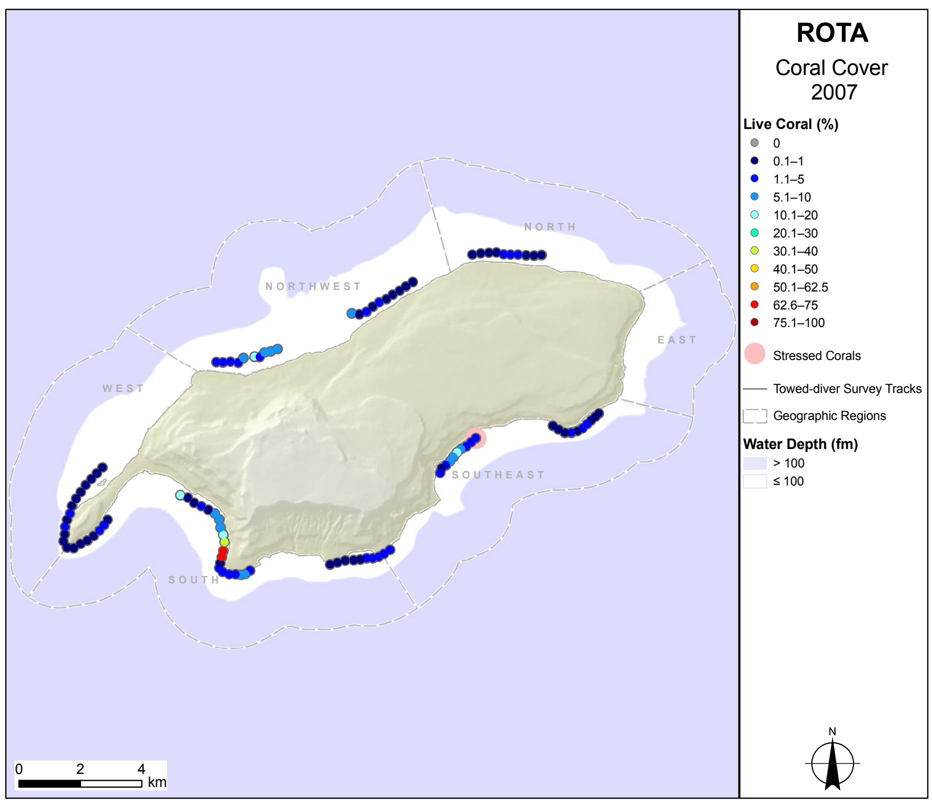



**Figure 5.5.1e.** Cover (%) observations of live and stressed hard corals from towed-diver benthic surveys of forereef habitats conducted at Rota during MARAMP 2007. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of ~ 200 x 10 m (~ 2000 m$^2$). Pink symbols represent segments where estimates of stressed-coral cover were > 10%. Stressed-coral cover was measured as a percentage of overall coral cover.




During MARAMP 2007, 6 REA benthic surveys using the line-point-intercept method were conducted on forereef habitats at Rota. Site-specific estimates of live-hard-coral cover from these surveys ranged from 2% to 34.3% with an overall sample mean of 12.4% (SE 5.4). The highest coral cover was observed at ROT-03 in the south region near Puntan Pona, and the lowest coral cover was recorded west of Puntan Sagua`gahga at ROT-02 in the southeast region (Fig. 5.5.1.f).

During MARAMP 2007, 6 REA benthic surveys using the belt-transect method on forereef habitats at Rota documented 1307 coral colonies within a total survey area of 300 $m^2$. Site-specific colony densities ranged from 2.3 to 6.8 colonies $m^{-2}$ with an overall sample mean of 4.4 colonies $m^{-2}$ (SE 0.6). Similar to results from MARAMP 2005 surveys, the highest colony density was observed at ROT-06 in the west region, and the lowest colony density was recorded at ROT-02 in the southeast region (Fig. 5.5.1.f).

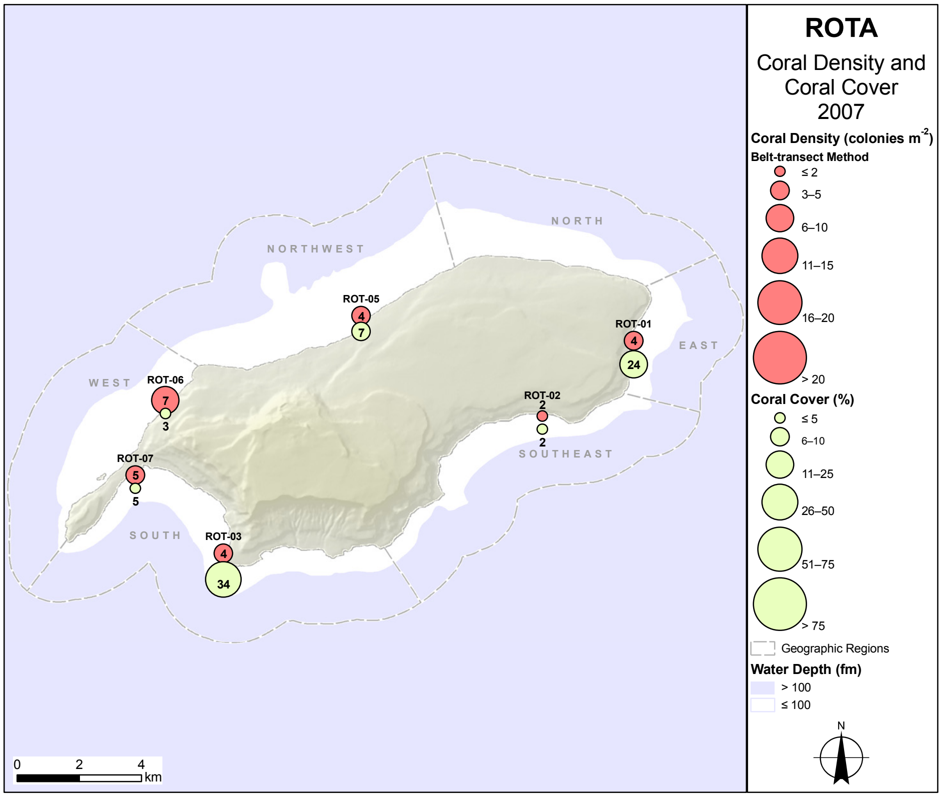



**Figure 5.5.1f.** Cover (%) and colony-density (colonies $m^{-2}$) observations of live hard corals from REA benthic surveys of forereef habitats conducted at Rota during MARAMP 2007. Values are provided within of below each symbol. The belt-transect method was used in 2007 to assess coral-colony density.

Islandwide mean cover of live corals, estimated from towed-diver surveys of forereef habitats, varied slightly between survey years, falling from 9% (SE 1) in 2003 to 6% (SE 1) in 2005 and 4% (SE 1) in 2007 (Fig. 5.5.1g). This variation in overall mean values of live coral cover between MARAMP survey years is not necessarily indicative of actual changes in overall coral cover (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys"). Estimates of live coral cover from REA surveys generally exceeded levels recorded in towed-diver surveys; REA surveys target hard-bottom communities, whereas towed-diver surveys include a wider array of substrate types. Site-specific estimates of coral cover averaged 12.4% (SE 5.4) for the 6 REA sites surveyed in 2007 (Rota was not surveyed for coral cover using the line-point-intercept method in 2003 and 2005).

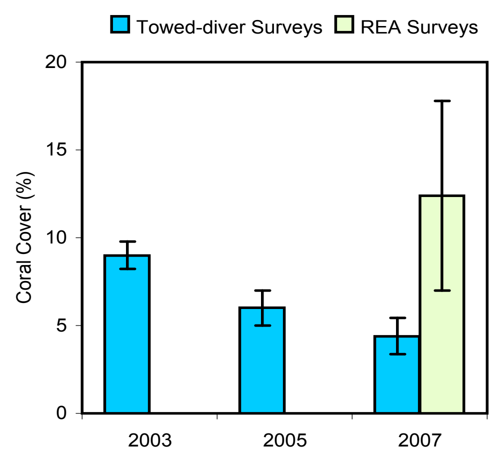



**Figure 5.5.1g.** Temporal comparison of mean live-coral-cover (%) values from REA and towed-diver benthic surveys conducted on forereef habitats around Rota during MARAMP 2003, 2005, and 2007. No REA surveys using the line-point-intercept method were conducted around Rota in 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.

The decrease in live coral cover near Puntan Sailigai in the northwest region, from a mean of 25% in 2003 to means of 10% in 2005 and 6% in 2007 over 10 segments, may also result from spatial variation in track locations and depths between survey years (Fig. 5.5.1g). However, elevated levels of stressed-coral cover recorded in 2005 may hint at additional reasons for the decline near this point.

During the 3 MARAMP survey periods, high levels of coral cover were recorded in the survey area in Coral Gardens in the south region, com-

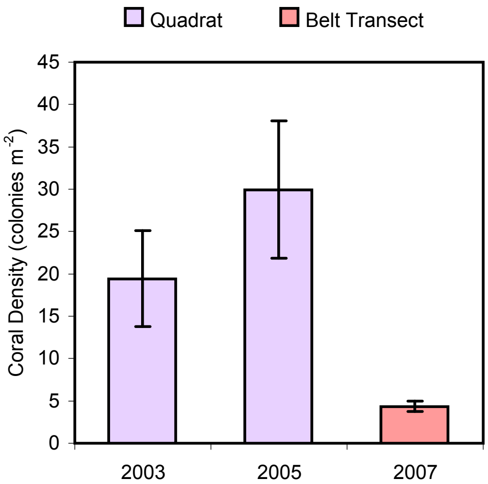



**Figure 5.5.1h.** Temporal comparison of mean coral-colony densities (colonies m$^{-2}$) from REA benthic surveys conducted on forereef habitats at Rota during MARAMP 2003, 2005, and 2007. The quadrat method was used in 2003 and 2005 to measure coral-colony density, but the belt-transect method was used in 2007. Error bars indicate standard error (± 1 SE) of the mean.

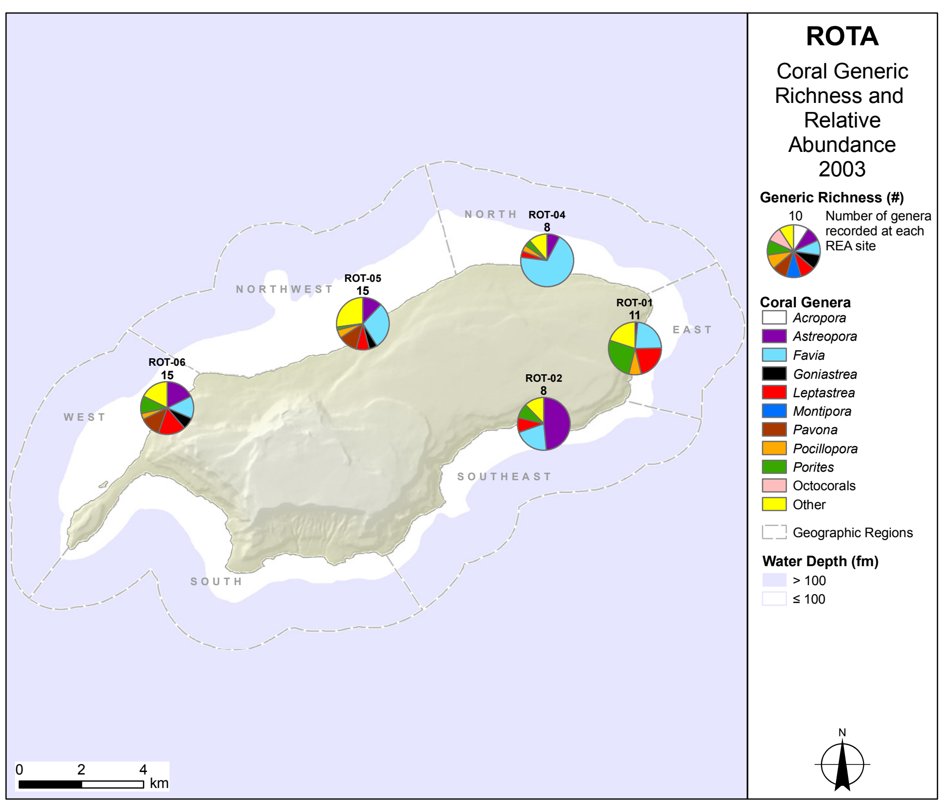
pared to results from other towed-diver-survey areas at Rota. Observed coral cover in this area varied between survey years: 24% for 7 segments in 2003, 49% for 3 segments in 2005 and 58% for 3 segments in 2007.

Overall mean coral-colony density from REA benthic surveys of forereef habitats at Rota did not change significantly between MARAMP 2003 and 2005, when the quadrat method was used, with 19.4 colonies m$^{-2}$ (SE 5.7) and 30 colonies m$^{-2}$ (SE 8.1), respectively (Fig. 5.5.1h). At each of the 4 sites surveyed in both years (ROT-01, ROT-02, ROT-05, and ROT-06), observed colony density increased between 2003 and 2005. This increase could result from recruitment, fragmentation of existing colonies, or both. Site-specific coral-colony densities and overall mean density were substantially lower in 2007 than in 2003 and 2005. However, this decline is likely an artifact of the use of a different method, the belt-transect method, to assess colony density in 2007. The method of placing quadrats used in 2003 and 2005 was highly biased towards surveying hard-bottom substrate where corals were present, whereas the belt-transect method used in 2007 assessed benthos that fell within transect belts regardless of the nature of the substrate.

### *Coral Generic Richness and Relative Abundance*

Five REA benthic surveys of forereef habitats were conducted using the quadrat method at Rota during MARAMP 2003. At least 18 coral genera were observed at Rota. Generic richness ranged from 8 to 15 with a mean of 11.4 (SE 1.6) coral genera per site. The highest generic diversity was seen at both ROT-05 and ROT-06 in the northwest and west regions, and the lowest generic diversity was recorded at both ROT-02 and ROT-04 in the southeast and north regions (Fig. 5.5.1i).

**Figure 5.5.1i.** Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted at Rota during MARAMP 2003. The pie charts indicate percentages of relative abundance of key coral genera. The quadrat method was used in 2003 to assess generic richness.



*Favia*, *Astreopora, Leptastrea*, and *Porites* were the most numerically abundant genera, contributing 31.2%, 17.4%, 11.8%, and 10.4% of the total number of colonies enumerated at Rota during MARAMP 2003. All other genera individually contributed < 10% of the total number of colonies. *Favia* dominated the coral fauna at ROT-04 and ROT-05 in the north and northwest regions, contributing 69.2% and 28.7% of the total number of colonies (Fig. 5.5.1i). *Porites* and *Favia* co-dominated at ROT-01 in the east region, contributing 26.2% and 23.1% of the total number of colonies. *Astreopora* dominated at ROT-02 in the southeast region, contributing 48.5% of the total number of colonies.

Five REA benthic surveys of forereef habitats were conducted using the quadrat method at Rota during MARAMP 2005. At least 24 coral genera were observed at Rota. Generic richness ranged from 7 to 17 with a mean of 12.8 (SE 1.7) coral genera per site. The highest generic diversity was seen at ROT-05 in the northwest region, and the lowest generic diversity was recorded at ROT-02 in the southeast region (Fig. 5.5.1j).

*Favia*, *Porites*, *Leptastrea*, and *Astreopora* were the most numerically abundant genera, contributing 19.9%, 21.8%, 13.9%, and 11.4% of the total number of colonies enumerated at Rota during MARAMP 2005. All other genera individually contributed < 10% to the total number of colonies. *Favia* dominated the coral fauna at ROT-02 and ROT-05 in the southeast and northwest regions, contributing 44.7% and 18.2% of the total number of colonies (Fig. 5.5.1j). *Favia*, *Porites*, and *Leptastrea* were found at similar abundance levels at ROT-07 in East Harbor in the south region, contributing 19%, 21.4%, and 23.8% of the total number of colonies. *Porites* dominated at ROT-01 in the east region, contributing 57% of the total number of colonies.

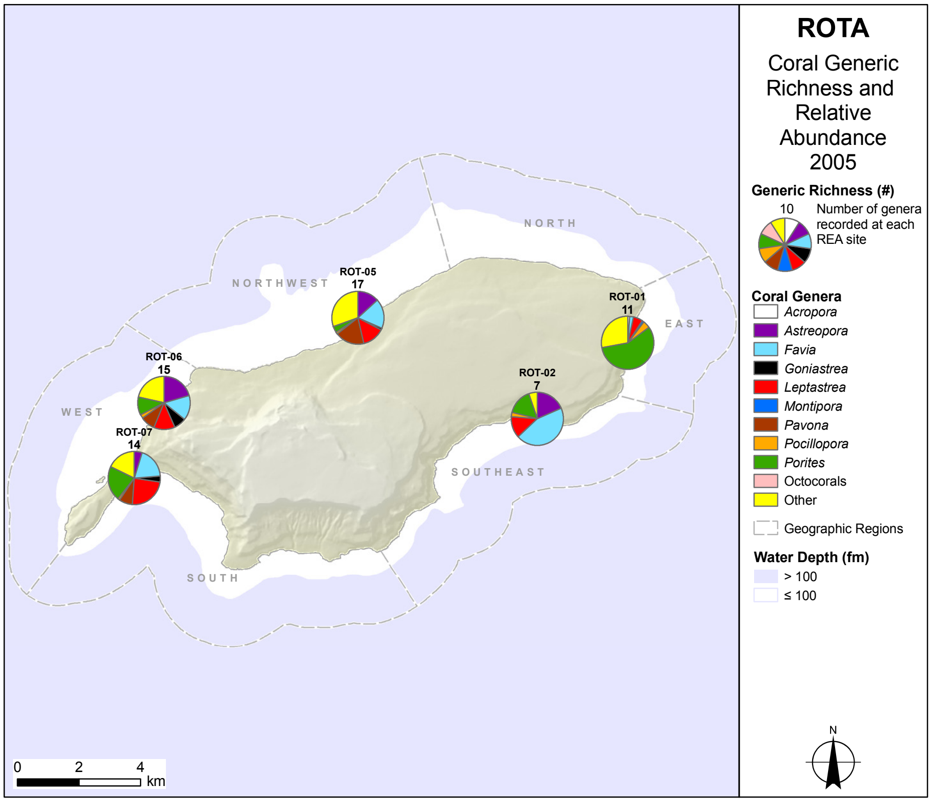



**Figure 5.5.1j.** Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted at Rota during MARAMP 2005. The pie charts indicate percentages of relative abundance of key coral genera. The quadrat method was used in 2005 to assess generic richness.

Six REA benthic surveys of forereef habitats were conducted using the belt-transect method at Rota during MARAMP 2007. At least 28 coral genera were observed at Rota, including the following 5 genera that had not been previously recorded at Rota in 2003 and 2005: *Cycloseris*, *Lobophytum*, *Palythoa*, *Sarcophyton*, and *Sinularia*. Generic richness ranged from 7 to 21 with a mean of 16.5 (SE 2.1) coral genera per site. The highest generic diversity was seen at ROT-07 in the south region, and the lowest generic diversity was recorded at ROT-03, also in the south region (Fig. 5.5.1k).

*Porites* and *Astreopora* were the most numerically abundant genera, contributing 35.4% and 11.2% of the total number of colonies enumerated at Rota during MARAMP 2007. All other genera individually contributed < 10% of the total number of colonies. *Porites* dominated the coral fauna at ROT-01, ROT-03, ROT-06, and ROT-07 in the east, south, and west regions, contributing 50.5%, 88.6%, 22.1%, and 40.3% of the total number of colonies (Fig. 5.5.1k). *Astreopora* dominated at ROT-02 and ROT-05 in the southeast and northwest regions, contributing 18.6% and 37.2% of the total number of colonies.

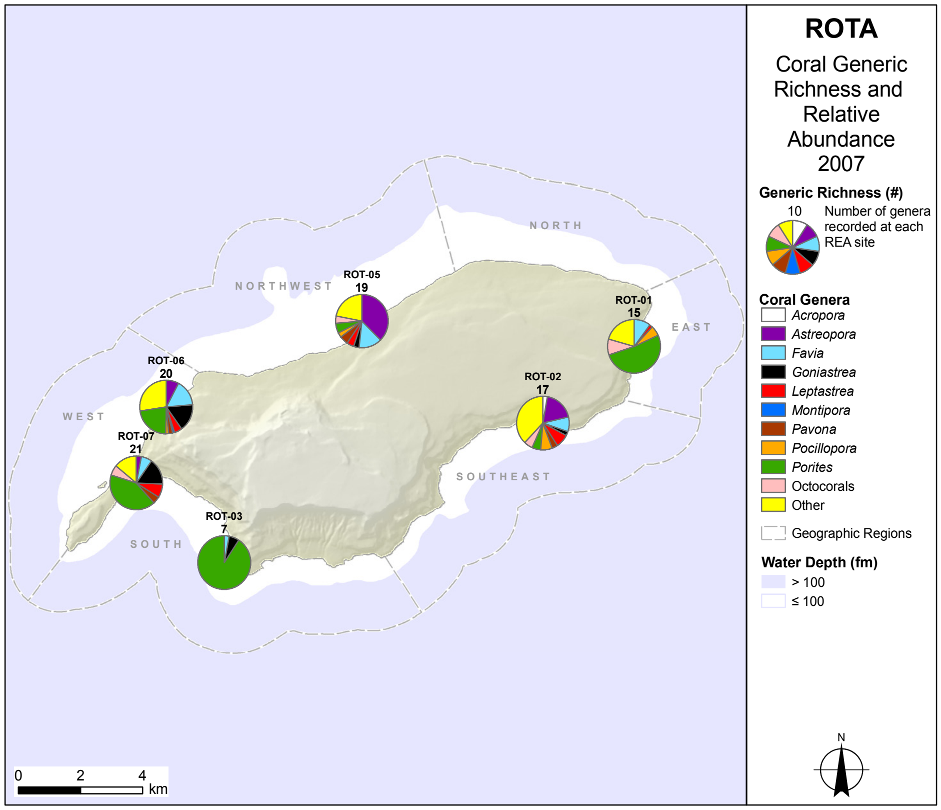



**Figure 5.5.1k.** Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted at Rota during MARAMP 2007. The pie charts indicate percentages of relative abundance of key coral genera. The belt-transect method was used in 2007 to assess generic richness.

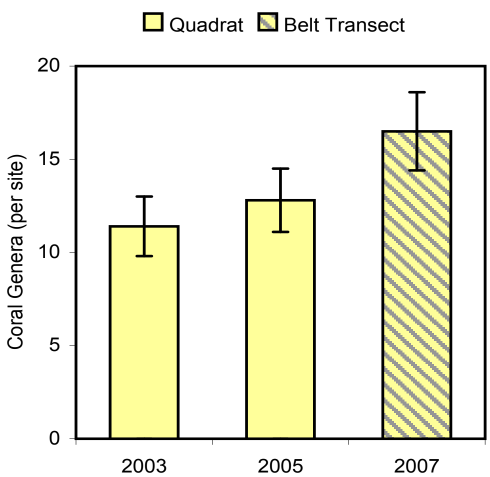



**Figure 5.5.1l.** Temporal comparison of overall mean numbers of coral genera per site from REA benthic surveys conducted on forereef habitats at Rota during MARAMP 2003, 2005, and 2007. The quadrat method was used in 2003 and 2005 to survey coral genera, but the belt-transect method was used in 2007. Error bars indicate standard error (± 1 SE) of the mean.

Site-specific estimates of generic richness across the 3 MARAMP survey years ranged from 7 to 21 on forereef habitats at Rota. Site-specific and overall mean values of generic richness were higher in 2007 than in previous survey years (Fig. 5.5.1l). The overall mean was 16.5 (SE 2.1) coral genera per site in 2007 and 11.4 (SE 1.6) and 12.8 (SE 1.7) coral genera per site in 2003 and 2005. This increase is likely a result of the difference in the size of the areas in which corals were censused: the survey area in 2007 was 50 $m^2$ per site, much larger than the 3.75–4 $m^2$ per site surveyed in 2003 and 2005 (see Chapter 2: "Methods and Operational Background," Section 2.4.5: "Corals and Coral Disease"). Additionally, the only octocoral genus assessed in 2003 and 2005 was *Heliopora*, whereas all octocoral genera were assessed in 2007.

Across the 3 MARAMP survey periods, 31 coral genera were observed on forereef habitats at Rota. *Favia*, *Porites*, *Astreopora*, and *Leptastrea* were important components of the coral fauna. *Favia* was the most numerically abundant taxon in 2003 and 2005, contributing 31.2% and 19.9% of the total number of colonies enumerated at Rota. *Porites* was the most numerically abundant taxon in 2007, contributing 35.4% of the total number of colonies. *Astreopora* was the second-most numerically abundant taxon in 2003 and 2007, contributing 17.4% and 11.2% of the total number of colonies. *Leptastrea* was the third-most numerically abundant taxon in 2003 and 2005, contributing 11.8% and 13.9% of the total number of colonies.

### *Coral Size-class Distribution*

During MARAMP 2003, 5 REA benthic surveys of forereef habitats were conducted at Rota using the quadrat method. The coral size-class distribution from these surveys shows that the majority (75.5%) of corals had maximum diameters ≤ 5 cm (Fig. 5.5.1m). The next 3 size classes (6–10, 11–20, and 21–40 cm) accounted for 18.1%, 4.5%, and 1.9% of colonies recorded. No colonies with a maximum diameter > 40 cm were recorded. At each of the 5 REA sites, the majority (63%) of corals were in the smallest (≤ 5 cm) size class.

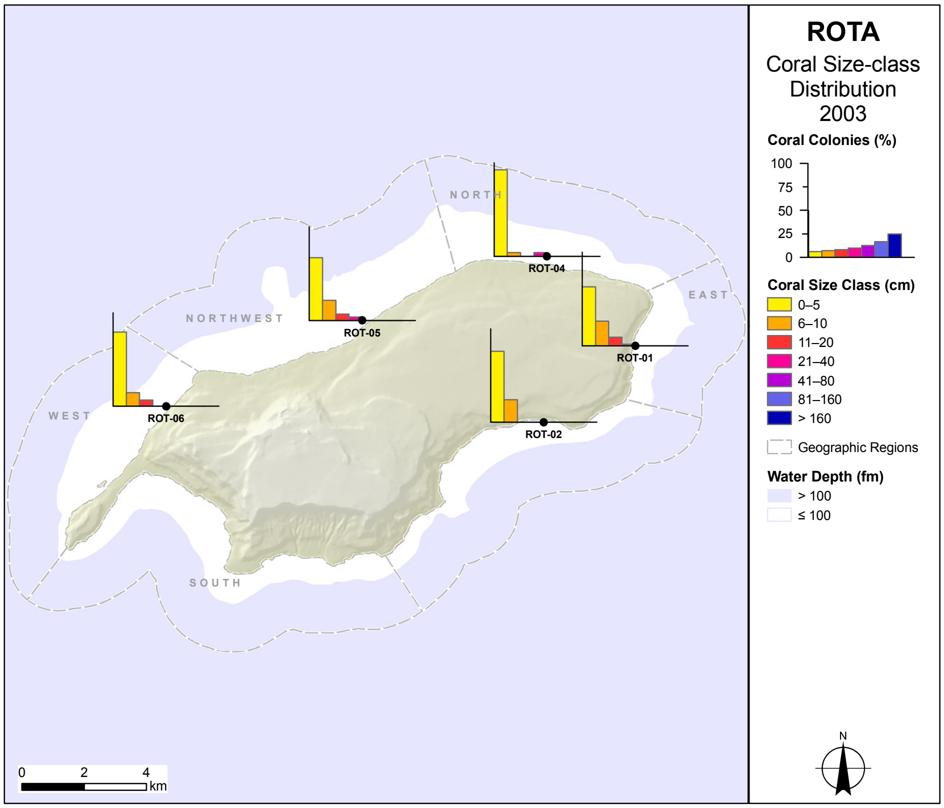



**Figure 5.5.1m.** Size-class distributions of hard corals from REA benthic surveys of forereef habitats conducted at Rota during MARAMP 2003. The observed size classes are color coded in a size-frequency chart at each REA site. The quadrat method was used in 2003 to size corals.

During MARAMP 2005, 5 REA benthic surveys of forereef habitats were conducted at Rota using the quadrat method. The coral size-class distribution from these surveys shows that the majority (86%) of corals had maximum diameters ≤ 5 cm (Fig. 5.5.1n). The next 3 size classes (6–10, 11–20, and 21–40 cm) accounted for 9%, 3.6%, and 1.4% of colonies recorded. No colonies with a maximum diameter > 40 cm were recorded. At each of the 5 REA sites, the majority (> 69%) of corals were in the smallest (≤ 5 cm) size class.

During MARAMP 2007, 6 REA benthic surveys of forereef habitats were conducted at Rota using the belt-transect method. The coral size-class distribution from these surveys shows that the majority (76.9%) of corals had maximum diameters ≤ 10 cm (Fig. 5.5.1o). The first 5 size classes (0–5, 6–10, 11–20, 21–40, and 41–80) accounted for 35.2%, 41.7%, 14.8 %, 6.2%, and 1.6% of colonies recorded. Only 0.6% of corals had a maximum diameter > 80 cm. The highest proportions of midsize (11–40 cm) and large (> 40 cm) colonies combined were found at ROT-01 and ROT-05 in the east and northwest regions, contributing 43.2% and 34.3% of colonies recorded, respectively. The highest proportion of small (≤ 10 cm) colonies was found at ROT-02 and ROT-06 in the southeast and west regions, accounting for 99.1% and 91.1% of colonies recorded.

Site-specific and overall distributions of estimated coral size classes on forereef habitats at Rota are affected by inherent biases in the methods used to census and size corals. During MARAMP 2003 and 2005, corals whose center fell within the borders of a quadrat (50 × 50 cm) were tallied and measured in 2 planar dimensions to the nearest centimeter. Fewer large colonies than small colonies can fall within a quadrat. This bias can contribute to higher counts of colonies in the smallest size classes and lower counts of colonies in the largest size classes compared to the actual relative colony densities. At each site, 15 or 16 such quadrats were examined (total survey area = 3.75 or 4 $m^2$), enabling observers to closely inspect and record each coral colony within the quadrat. During MARAMP 2007, corals whose center fell within a belt transect (1 × 25 m) were tallied and binned into 1 of 7 size classes based on visual estimates of maximum colony diameter. This method is better suited to capturing large colonies, but the larger census area likely reduces the number of very small colonies (≤ 5 cm) that are observed and recorded. For more on these survey methods, see Chapter 2: "Methods and Operational Background," Section 2.4.5, "Corals and Coral Disease."

**Figure 5.5.1n.** Size-class distributions of hard corals from REA benthic surveys of forereef habitats conducted at Rota during MARAMP 2005. The observed size classes are color coded in a size-frequency chart at each REA site. The quadrat method was used in 2005 to size corals.

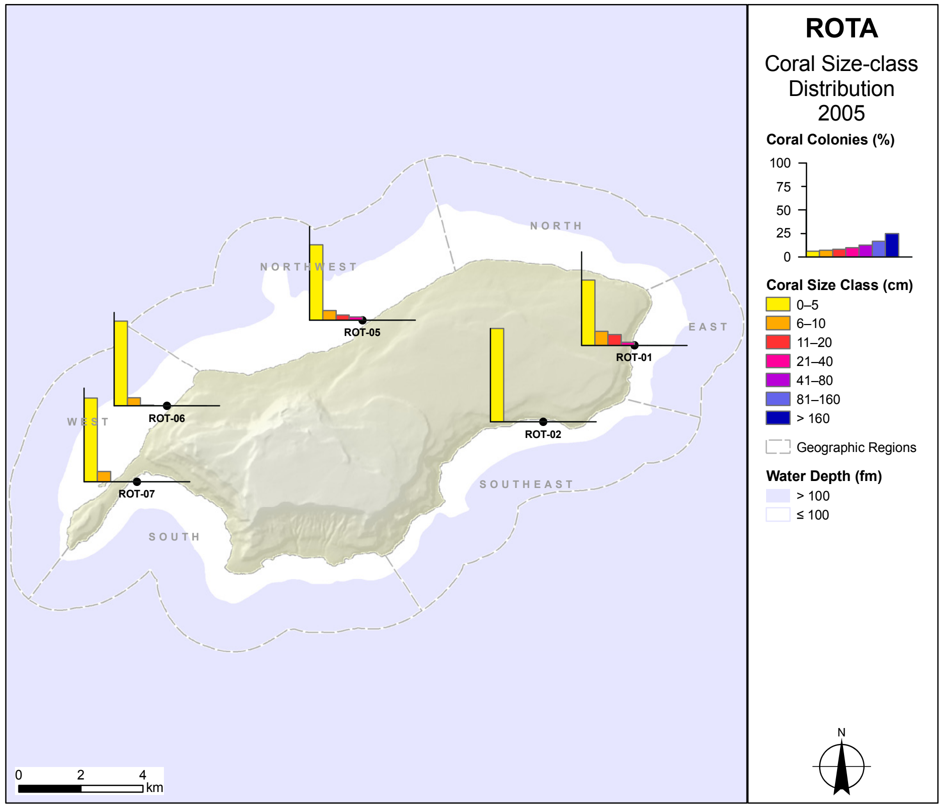
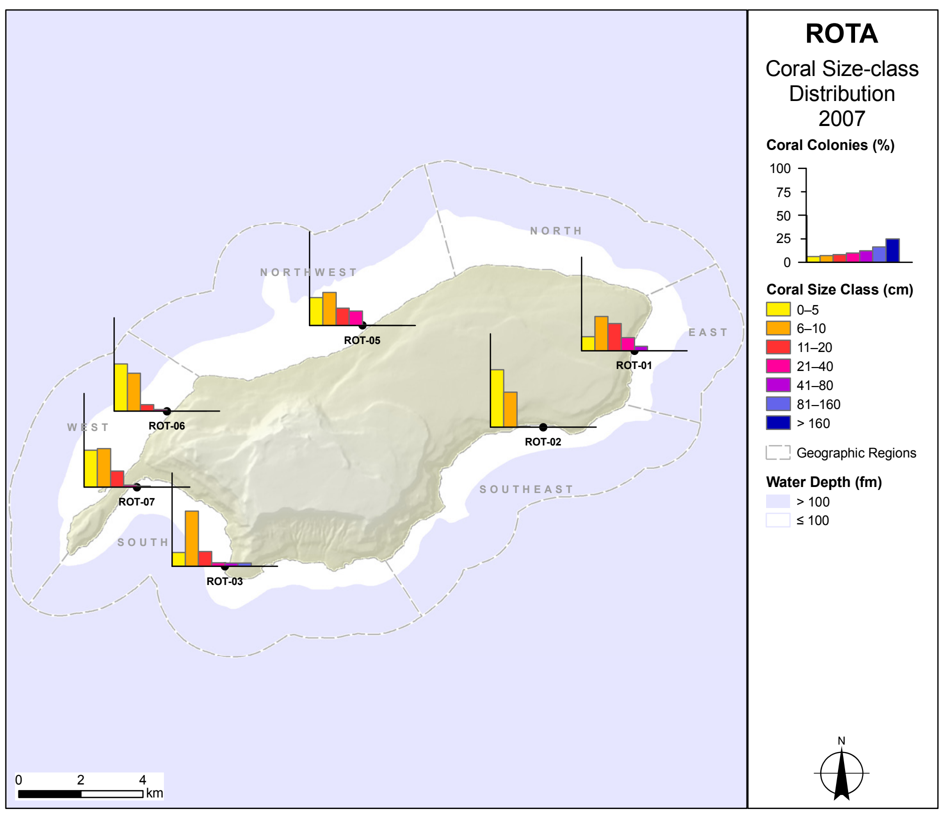



**Figure 5.5.1o.** Size-class distributions of hard corals from REA benthic surveys of forereef habitats conducted at Rota during MARAMP 2007. The observed size classes are color coded in a size-frequency chart at each REA site. The belt-transect method was used in 2007 to size corals.



These methodological biases are reflected in the size-class data by survey year. Observed colony densities were higher in in 2003 and 2005 than in 2007 (Fig. 5.5.1p). In 2003 and 2005, more than three-quarters (75.5% and 86.2%) of all colonies censused on forereef habitats at Rota had a maximum diameter ≤ 5 cm, but in 2007 only 35.2% of colonies fell into this smallest size class (Fig. 5.5.1p). Comparing size-class data between survey years when different methods were used is, therefore, inappropriate. Only ROT-01, ROT-02, ROT-05, and ROT-06 in the east, southeast, northwest, and west regions were surveyed with the same quadrat method in 2003 and 2005. At all 4 REA sites, between these 2 survey periods, the proportion of colonies in the smallest size class (≤ 5 cm) increased substantially and the proportion of colonies in other size classes decreased, suggesting that either increased recruitment, colony fragmentation, or both occurred during this period.

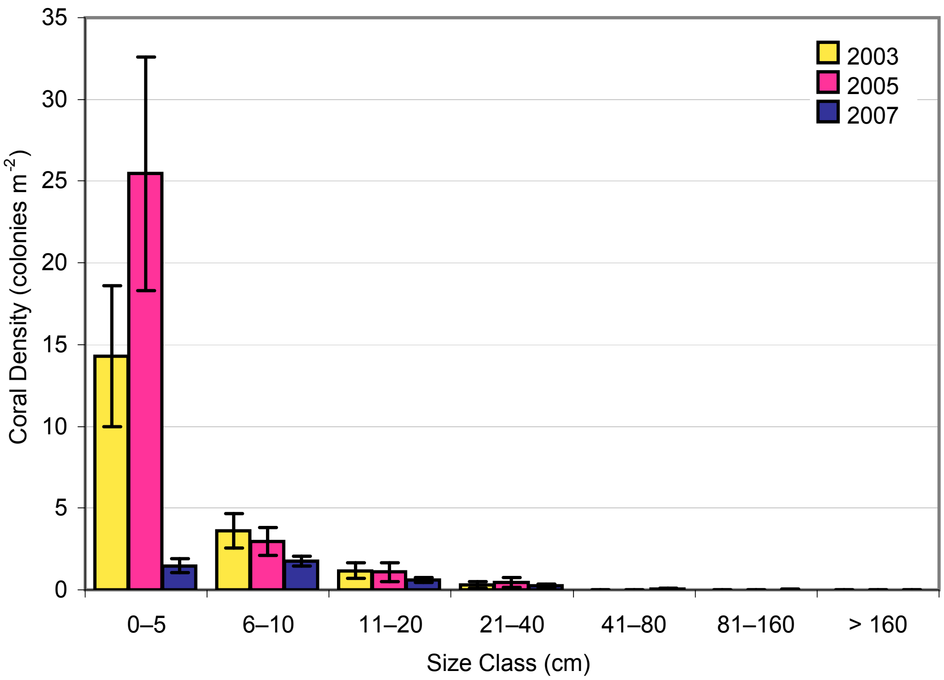



**Figure 5.5.1p.** Mean coral-colony densities (colonies $m^{-2}$) by size class from REA benthic surveys of forereef habitats conducted at Rota during MARAMP 2003, 2005, and 2007. The quadrat method was used in 2003 and 2005 to size corals, but the belt-transect method was used in 2007. Error bars indicate standard error (± 1 SE) of the mean.

## 5.5.2 Surveys for Coral Disease and Predation

During MARAMP 2007, REA benthic surveys for coral disease and predation were conducted on forereef habitats using the belt-transect method at 6 sites at Rota, covering a total area of over 1700 $m^2$. Surveys detected 5 cases of coral disease, translating to an overall mean prevalence of 0.06% (SE 0.03), excluding predation. Bleaching was the only disease state observed at Rota, detected at ROT-01, ROT-05, and ROT-06 in the east, west, and northwest regions. Relative to colony density, the highest value of disease prevalence was 0.17%, observed at ROT-05 (Fig. 5.5.2a; the values of overall prevalence shown in this figure include predation). All cases of bleaching at Rota were recorded on corals of the genus *Astreopora*.

Cases of coral predation attributable to crown-of-thorns seastars (*Acanthaster planci)* or corallivorous snails, such as snails from the genus *Drupella*, were also observed at Rota, particularly at ROT-03 near Puntan Pona in the south region and at ROT-06 southwest of Puntan Sailigai in the west region (Fig. 5.5.2b). A variety of coral genera were the main prey of crown-of-thorns seastars (COTS) and snails, including *Pavona*, *Stylophora*, *Goniastrea*, *Pocillopora*, *Astreopora*, and *Porites*, with the greatest number of cases (40%) detected on *Astreopora* corals. For more information about COTS at Rota, see Section 5.7.1: "Benthic Macroinvertebrate Surveys".

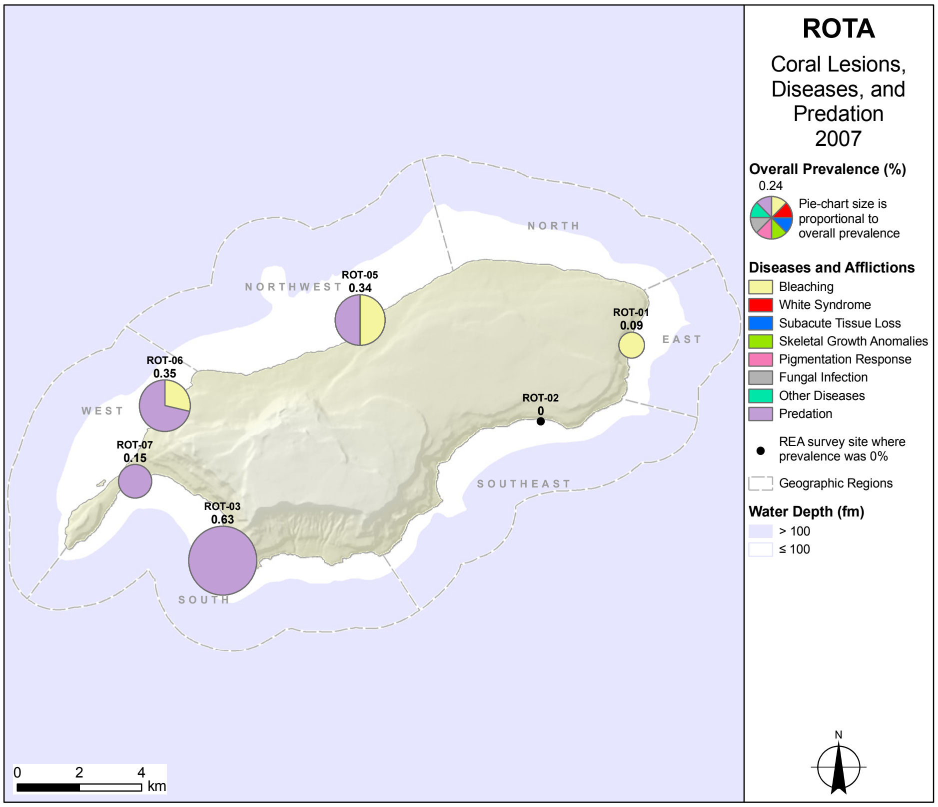



**Figure 5.5.2a.** Overall prevalence (%) observations of coral diseases and predation from REA benthic surveys of forereef habitats conducted at Rota during MARAMP 2007. Prevalence was computed based on the estimated total number of coral colonies within the area surveyed for disease at each REA site. The color-coded portions of the pie charts indicate disease-specific prevalence.

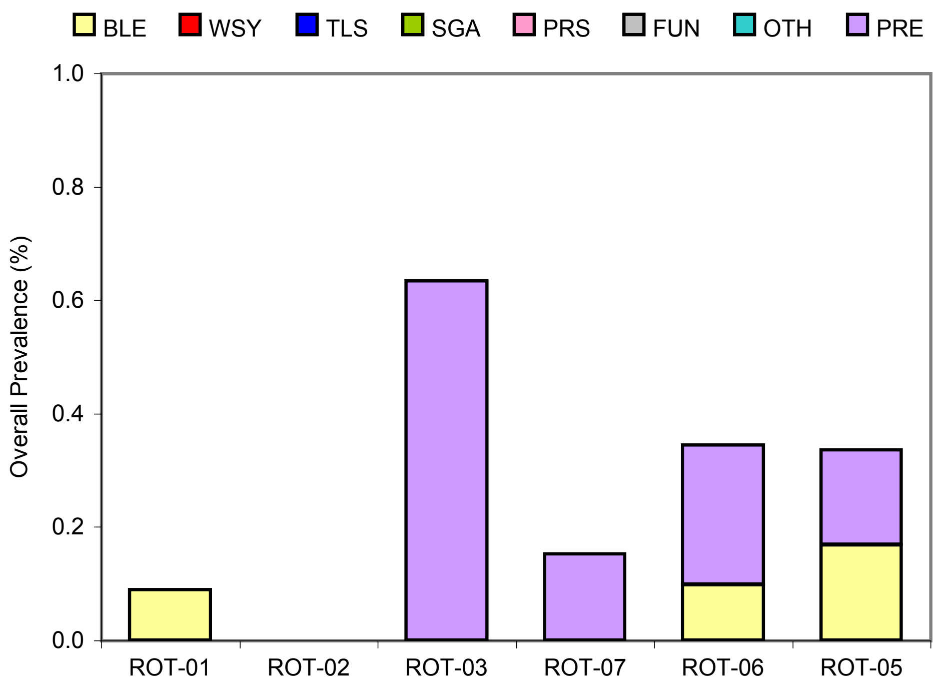



**Figure 5.5.2b.** Overall prevalence (%) observations of coral diseases and predation from REA benthic surveys of forereef habitats conducted at Rota during MARAMP 2007. Prevalence was computed based on the estimated total number of coral colonies within the area surveyed for disease at each REA site. The order of conditions presented in the bars is the same as the order in the legend. BLE: bleaching; WSY: white syndrome; TLS: subacute tissue loss; SGA: skeletal growth anomalies; PRS: pigmentation response; FUN: fungal infection; OTH: algal and cyanophyte infections and other lesions of unknown etiology; PRE: predation by COTS or corallivorous snails.

## 5.6 Algae and Algal Disease

### 5.6.1 Algal Surveys

#### *Algal Cover: Macroalgae and Turf Algae*

From MARAMP 2003 towed-diver surveys, mean macroalgal cover on forereef habitats around the island of Rota was 54% (SE 1.6). Observations of macroalgal cover in 2003 included both macroalgae and turf algae (see Chapter 2: "Methods and Operational Background"). The survey with the highest mean macroalgal cover of 77%, within a range of 50.1%–100%, occurred in the east region (Fig. 5.6.1a, top left panel). In this area, pavement was the dominant habitat type, with low complexity observed over 6 segments. The second-greatest mean macroalgal cover of 76%, within a range of 62.6%–100%, was recorded during a survey in the north region, where the dominant habitat was pavement for all segments; low complexity was observed for the majority of segments. The survey with the lowest macroalgal cover of 30%, within a range of 20.1%–40%, occurred in the northwest region in a mostly continuous-reef habitat of medium to high complexity, with half of the observations characterizing complexity at medium-high.

TOAD surveys completed at Rota during MARAMP 2003 were conducted at depths of 53–188 m. Analyses of TOAD video footage obtained from 7 surveys in the west, south, and southeast regions suggest that macroalgal cover was generally low in these areas (Fig. 5.6.1a, top left panel). In some small sections, these surveys recorded macroalgal cover up to 100%, but no macroalgae were observed in the majority of images. In contrast, analyses of TOAD video footage obtained from 2 surveys in the north region suggest sections with consistent macroalgal cover of 20.1–100%. Similarly, 1 survey in the northwest region recorded, over the southern end of its track, consistent macroalgal cover of 40.1%–100% at depths of 83–100 m.

From MARAMP 2005 towed-diver surveys, mean cover of macroalgae on forereef habitats at Rota was 56% (SE 2). The survey with the highest mean macroalgal cover of 71%, within a range of 40.1%–100%, occurred in the northwest region over a low-complexity habitat (Fig. 5.6.1a, middle left panel). No data were recorded on the dominant habitat type during towed-diver surveys conducted in 2005. The survey with the lowest mean macroalgal cover of 37%, within a range of 10.1%–50%, occurred in the south region in Sasanhaya Bay near REA site ROT-03 over habitat of mixed complexity that ranged from medium-low to high (for place-names and their locations, see Figure 5.2a in Section 5.2: "Survey Effort").

From MARAMP 2007 towed-diver surveys, mean cover of macroalgae on forereef habitats at Rota was 39% (SE 2). The survey with the highest mean macroalgal cover of 69%, within a range of 40.1%–100%, occurred in the southeast region west of Puntan Sagua`gahaga (Fig. 5.6.1a, bottom left panel). Habitat in this area was primarily of medium-low complexity, and species of the green algal genera *Halimeda* and *Microdictyon* were observed during all survey segments, with *Microdictyon* the dominant genera for 6 of the 10 segments. The survey with the lowest mean macroalgal cover of 13%, within a range of 1.1%–30%, occurred in the south region near Puntan Pona. In this area, habitat complexity ranged from medium-low to high, and an abundance of turf, brown, and red cyanobacteria was observed over the first 6 segments.

During MARAMP 2007, 6 REA benthic surveys of forereef habitats at Rota were conducted using the line-point-intercept method. Site-specific estimates of macroalgal cover ranged from 0% to 49% with an overall mean of 20% (SE 7.2). The survey with the highest macroalgal cover occurred in the southeast region at ROT-02 (Fig. 5.6.1b). All other surveys recorded macroalgal cover ≤ 27.5%. No macroalgae were found at ROT-07 in the south region in East Harbor.

Turf-algal cover from these REA benthic surveys ranged from 28.4% to 77.5% with an overall mean of 56% (SE 6.9). The highest turf-algal cover was observed at ROT-07 (Fig. 5.6.1b). High levels of turf-algal cover were also found in the northwest region at ROT-05, with a value of 62.7%, and in the west region at ROT-06. The lowest turf-algal cover was recorded in the southeast region at ROT-02.

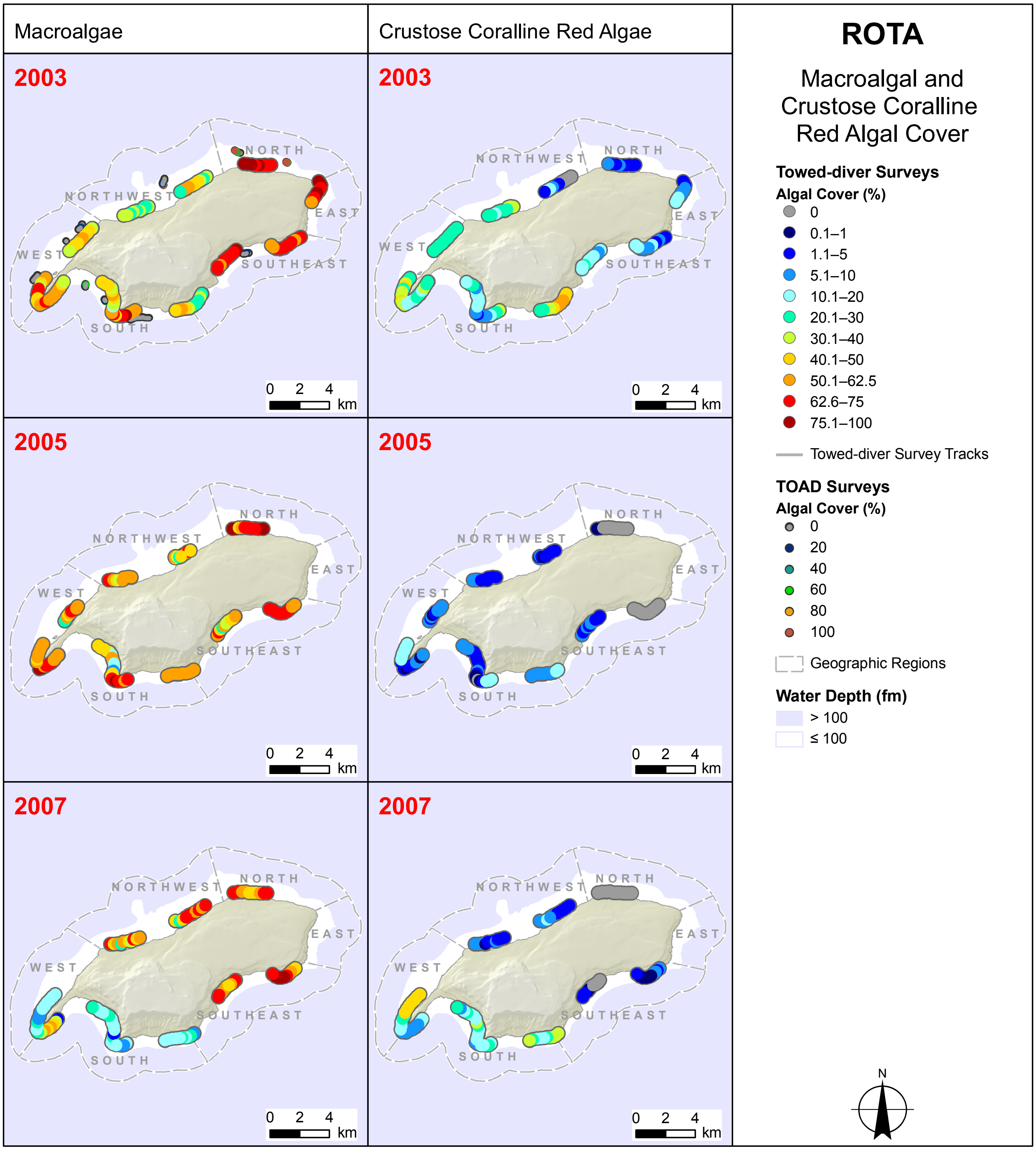



**Figure 5.6.1a.** Cover (%) observations for macroalgae and crustose coralline red algae from towed-diver benthic surveys of forereef habitats conducted at Rota during MARAMP 2003, 2005, and 2007. Each large, colored point represents an estimate over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m$^2$). The 2003 macroalgal panel shows observations of both macroalgae and turf algae (towed-diver surveys included turf algae only during MARAMP 2003). In this panel, each small, colored point represents an estimate of algal cover from TOAD surveys.

## *Algal Cover: Crustose Coralline Red Algae*

From MARAMP 2003 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Rota was 18% (SE 1). The survey with the highest mean cover of crustose coralline red algae of 34%, within a range of 20.1%–50%, occurred in the west region (Fig. 5.6.1a, top right panel), where pavement was the dominant habitat and complexity was predominantly medium-high with 1 segment of high and 2 segments of medium complexity. The survey with the lowest mean crustose-coralline-red-algal cover of 4%, within a range of 1.1%–10%, occurred in the north region near Mochon Point over habitat that was primarily low complexity pavement.

From MARAMP 2005 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats at Rota was 5% (SE 0.44). The survey with the highest cover of 13%, within a range of 1.1%–20%, occurred in the west region over habitat of medium to medium-low complexity (Fig. 5.6.1a, middle right panel). Surveys with no crustose coralline red algae occurred over predominantly low-complexity habitat in the north region west of Mochon Point and in the southeast region near Puntan Sagua`gahga. During the survey conducted in the southeast region, the diver noted "a grey cylindrical sponge everywhere" for the first 6 segments.

From MARAMP 2007 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats at Rota was 12% (SE 1). The survey with the highest mean cover of crustose coralline red algae of 38%, within a range of 10.1%–50%, occurred in the west region (Fig. 5.6.1a, bottom right panel), where habitat was primarily of medium-high complexity and a variety of habitat types were encountered, including continuous reef, steep wall, moderate slope with boulders at the bottom, spur and groove, and pavement. In the north region near Mochon Point, a survey found no crustose coralline red algae. Habitat in this area was predominantly flat continuous reef of medium-low complexity, except for the first 2 segments where pavement was the dominant habitat and species of the green algal genus *Halimeda* and the brown algal genus *Padina* were recorded.

During MARAMP 2007, REA benthic surveys of forereef habitats at Rota were conducted using the line-point-intercept method. Site-specific estimates of crustose-coralline-red-algal cover ranged from 0% to 9.8% with an overall mean of 5% (SE 1.6). The REA survey with the highest crustose-coralline-red-algal cover occurred in the east region at ROT-01 (Fig. 5.6.1b). No crustose coralline red algae were recorded in the southeast region at ROT-02.

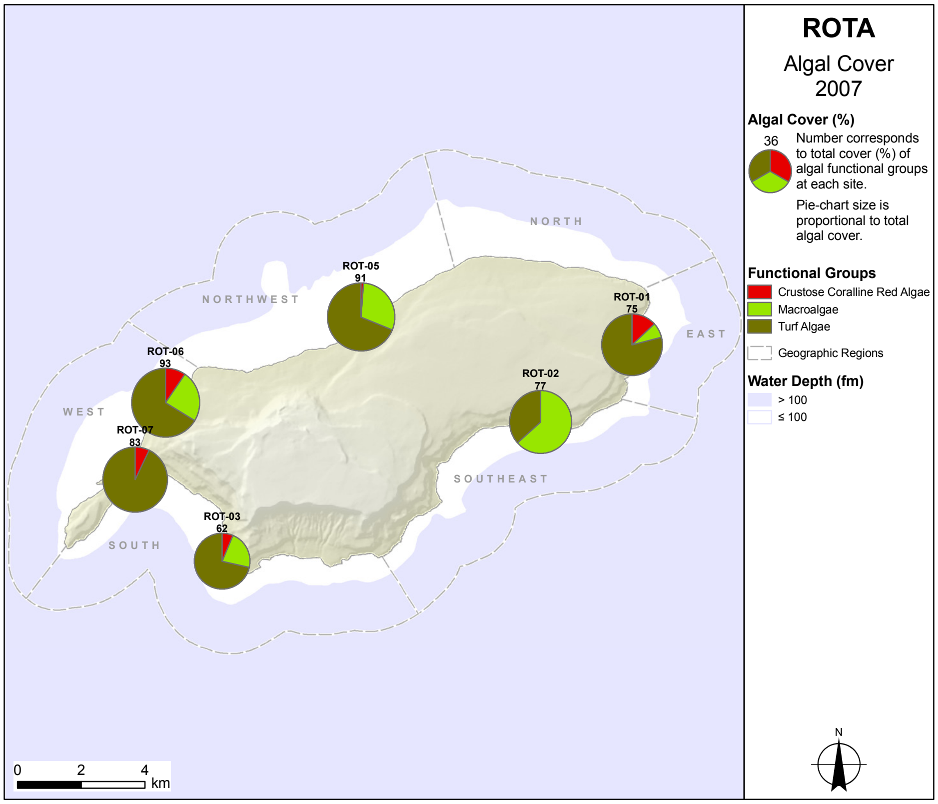



**Figure 5.6.1b.** Observations of algal cover (%) from REA benthic surveys of forereef habitats conducted using the line-point-intercept method at Rota during MARAMP 2007. The pie charts indicate algal cover by functional group, and values of total algal cover are provided above each symbol.

### Algal Cover: Temporal Comparison

Islandwide mean cover of macroalgal populations around Rota, based on towed-diver surveys of forereef habitats, was nearly identical in 2003 and 2005 (Fig. 5.6.1c) with 54% (SE 2) and 56% (SE 2) and was lower in 2007 at 39% (SE 2). When considering survey results, keep in mind that turf algae were included, along with macroalgae, in towed-diver surveys of macroalgal cover only in 2003. Other factors, such as a change in season between survey periods, could have contributed to differences in algal cover (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

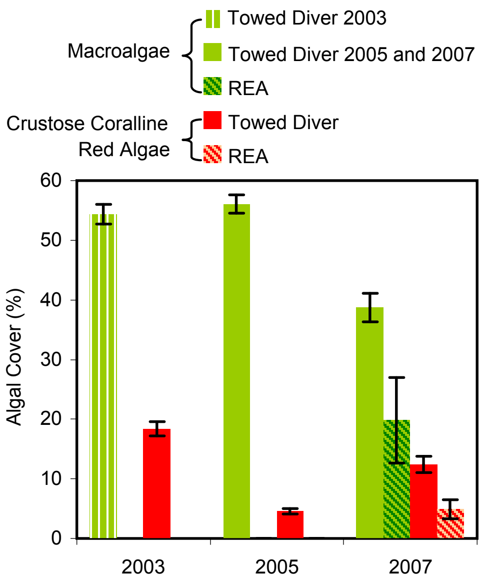



**Figure 5.6.1c.** Temporal comparison of algal-cover (%) values from surveys conducted on forereef habitats around Rota during MARAMP 2003, 2005, and 2007. Values of macroalgal cover from towed-diver surveys include turf algae only in 2003. No REA surveys using the line-point-intercept method were conducted at Rota in 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.

Across the 3 MARAMP survey years, high macroalgal cover was consistently recorded in the north and east regions during towed-diver surveys. The lowest levels of macroalgal cover were not quite as consistent but were observed in the south region in 2005 and 2007. In 2003, the lowest macroalgal cover occurred in the northwest region.

The observed overall mean cover of crustose coralline red algae on forereef habitats at Rota decreased from 18% (SE 1) in 2003 to 5% (SE 0.44) in 2005 and increased to 12% (SE 1) in 2007. The locations of the lowest and highest values in cover of crustose coralline red algae were consistent for the 3 MARAMP survey years. The towed-diver survey with the highest crustose-coralline-red-algal cover was always at the western tip of Rota. The survey with the lowest cover was always in the north region near Mochon Point, although, in 2005, no crustose coralline red algae were recorded in the southeast region near Puntan Sagua`gahga.

### Macroalgal Genera and Functional Groups

In the field, because of their small size or similarity in appearance, turf algae, crustose coralline red algae, cyanophytes (blue-green algae), and branched, nongeniculate coralline red algae were lumped into functional group categories. The generic names of macroalgae from field observations are tentative, since microscopic analysis is necessary for proper taxonomic identification. The lengthy process of laboratory-based taxonomic identification of all algal species collected at REA sites has not been undertaken yet for the southern islands of the Mariana Archipelago. Ultimately, based on microscopic analysis that may be done in the future, the generic names of macroalgae reported in this section may change and algal diversity reported for each REA site likely will increase.

During MARAMP 2003, REA benthic surveys were conducted at 5 sites on forereef habitats at Rota. In the field, 22 macroalgal genera (8 red, 3 brown, and 11 green), containing at least 29 species, as well as 4 additional algal functional groups—turf algae, crustose coralline red algae, cyanophytes, and branched calcified red algae—were observed. ROT-05 in the northwest region had the highest macroalgal generic diversity with 15 genera, containing 18 species, documented in the field. The lowest macroalgal generic diversity was found in the south region at ROT-03 near Puntan Pona and the Sasanhaya Fish Reserve with 3 species representing 3 genera recorded.

Chlorophytes were the most widely distributed algal taxa at every site surveyed at Rota in 2003. Species of the genus *Halimeda* were the most common component of macroalgal communities, occurring in 63.3% of sampled photoquadrats, and this green algal genus was the only genus recorded at all sites surveyed at Rota in 2003 (Fig. 5.6.1d). Species of the green algal genera *Microdictyon* and *Dictyosphaeria* were also common, occurring in 36.7% and 33.3% of sampled photoquadrats. Species of the green algal genus *Neomeris* were observed in 20% of sampled photoquadrats. Species of the green algal genus *Caulerpa* and the red algal genus *Laurencia* were equally numerous, each occurring in 16.7% of photoquadrats sampled at Rota. Species of the brown algal genus *Dictyota* occurred in 15% of sampled photoquadrats. Other observed genera occurred in < 10% of sampled photoquadrats. Green algal genera dominated at ROT-01 in the east region. Of the 12 species recorded in the field at this REA site, all but 1 was a green alga, and the genera *Halimeda, Dictyosphaeria, Microdictyon*, and *Neomeris* were very abundant. A similar pattern of high green algal abundance was observed near Puntan Sagua`gahga in the southeast region at ROT-02, where an additional green algal genus, *Bornetell*, was observed in 41.7% of sampled photoquadrats. Some genera were recorded with high frequency at a single site (for example, species of the genus *Laurencia* were found in 75% of photoquadrats sampled at ROT-02) but occurred in very few or none of the photoquadrats sampled at other sites, thus, greatly reducing their overall occurrence when considered on an islandwide scale. In addition to the diverse representation of green algae, species of red algal genera, such as *Dichotomaria*, *Galaxaura*, and *Portiera*, were observed frequently in ~ 25% of photoquadrats sampled at ROT-05 in the northwest region.

Turf algae, crustose coralline red algae, and cyanophytes were all common in 2003, occurring in 100%, 36.7%, and 48.3% of photoquadrats sampled at Rota. Recorded in all photoquadrats sampled at all sites, turf-algal communities were ubiquitous. Crustose coralline red algae were commonly observed at all sites except ROT-02 in the southeast region and typically varied in occurrence within a range of 25%–91.7%; however, branched coralline red algae were recorded in 8.3% of photoquadrats sampled at ROT-02. Cyanobacteria were found in 16.7%–83.3% of sampled photoquadrats.

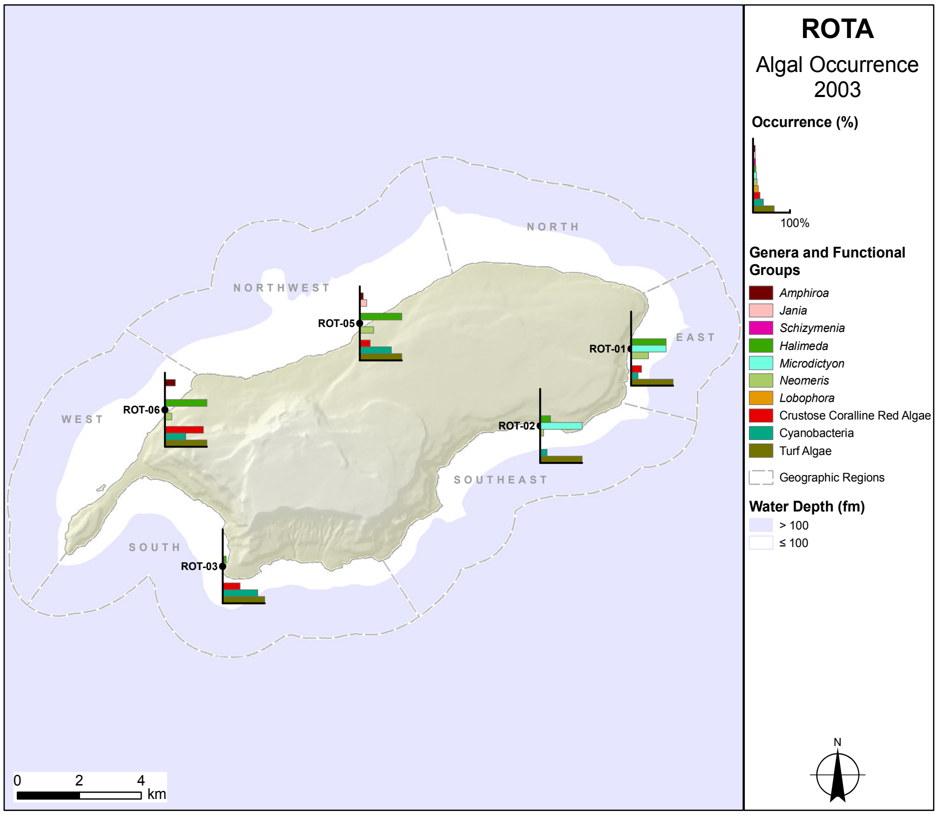



**Figure 5.6.1d.** Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys of forereef habitats conducted at Rota during MARAMP 2003. Occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. The length of the x-axis denotes 100% occurrence.

During MARAMP 2005, REA benthic surveys were conducted at 6 sites on forereef habitats at Rota. In the field, 23 macroalgal genera (7 red, 12 green, and 4 brown), containing at least 23 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanophytes—were observed. ROT-01 in the east region had the highest macroalgal generic diversity with 12 genera, each containing 1 species, documented in the field. The lowest macroalgal generic diversity was found in the southeast region at ROT-02 with 8 species representing 8 genera recorded.

No macroalgal genus was recorded at every site in 2005; however, species of the genus *Halimeda* were observed at all but one site and were the most widely distributed algae at Rota (Fig. 5.6.1e), occurring in 66.7% of sampled photoquadrats. Species of the genera *Dictyota* and *Dictyosphaeria* and the calcified red algal genera *Amphiroa* and *Jania* were all common, occurring in 38.9%, 34.7%, 29.2%, and 27.8% of sampled photoquadrats. Species of *Microdictyon* were recorded with frequent occurrence at 2 sites, ROT-01 (33.3%) and ROT-02 (75%), both of which also contained a high number of other green algal genera. Two thirds of the 12 genera recorded at ROT-01 were chlorophytes and were the only algal genera recorded in > 35% of sampled photoquadrats. At ROT-02, all 8 genera observed in the field were green algae. Since ROT-01 and ROT-02 are near each other in the east and southeast regions, it's reasonable to speculate that environmental conditions favor the growth of green algae in this region over brown or red algae. Furthermore, these sites supported a higher diversity and greater occurrence of green algae than was observed at nearby islands. Species of *Neomeris* were also fairly common, occurring in ≥ 25% of sampled photoquadrats at 5 of the 6 sites surveyed at Rota and in 26.4% of photoquadrats sampled overall at Rota. Other genera commonly encountered at Rota included *Galaxaura*, which occurred in 19.4% of photoquadrats sampled, largely resulting from its presence in 100% of photoquadrats sampled at ROT-05, and *Dictyota*, which occurred in 66.6%, 58.3%, 83.3%, and 25% of sampled photoquadrats at ROT-03, ROT-05, ROT-06, ROT-07.

Turf algae, crustose coralline red algae, and cyanobacteria were all common in 2005, occurring in 97.2%, 48.6%, and 88.9% of photoquadrats sampled at Rota. Turf-algal communities, ubiquitous at all sites, were found in 75%–100% of photoquadrats sampled at any given site. Recorded at every site, crustose coralline red algae were observed in 8.3%–100% of sampled photoquadrats, and cyanobacteria were a prominent component of the algal community at all sites, occurring in 66.7%–100% of sampled photoquadrats.

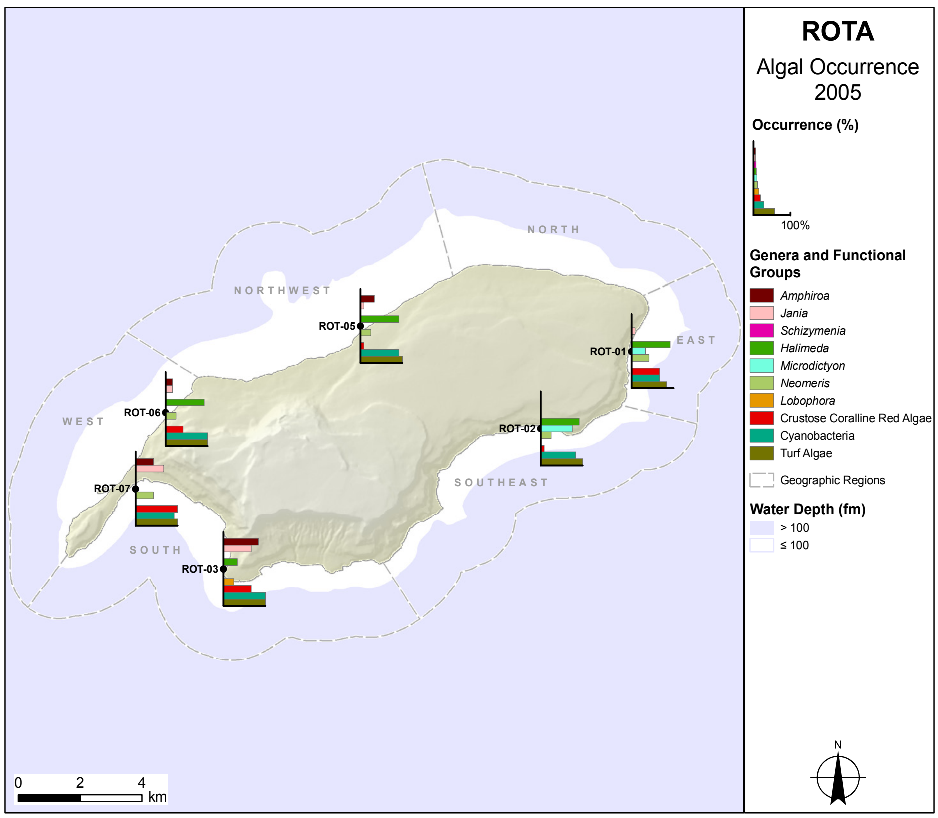



**Figure 5.6.1e.** Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys of forereef habitats at Rota during MARAMP 2005. Occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. The length of the x-axis denotes 100% occurrence.

During MARAMP 2007, REA benthic surveys were conducted at 6 sites on forereef habitats at Rota. In the field, 19 macroalgal genera (7 red, 10 green, and 2 brown), containing at least 28 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanophytes—were observed. ROT-05 in the northwest region had the highest macroalgal generic diversity with 11 genera, containing 13 species, documented in the field. The lowest macroalgal generic diversity was found in the south region at ROT-03 near Puntan Pona and Coral Gardens in the Sasanhaya Fish Reserve, with 5 species representing 5 genera recorded.

Species of the genus *Halimeda* were common at every site surveyed at Rota in 2007, except at ROT-07 in the south region in East Harbor, occurring in 72.2% of sampled photoquadrats at Rota (Fig. 5.6.1f). Of the 20 macroalgal species tentatively identified in the field, only a select few showed any spatial pattern of distribution, with no genus occurring at all sites. Species of the green alga genera *Halimeda*, *Neomeris*, and *Chlorodesmis* were each recorded at 4 of the 6 sites surveyed. Green algae dominated at ROT-01 and ROT-02 with only occasional observations of species of the brown algal genus *Padina*, the green algal genus *Rhipiliopsis*, and the red algal genera *Jania* and *Galaxaura.* Species of the genus *Amphiroa* were very common at ROT-03, near Puntan Pona in the south region, and ROT-05 in the northwest region, occurring in 91.7% and 75% of sampled photoquadrats, but far less common in East Harbor at ROT-07, where it occurred in only 25% of sampled photoquadrats. Despite the low occurrence of *Amphiroa* at ROT-07, this genus was the most frequently observed taxon because of the low abundance of the 5 other genera recorded at this site. Species of the genus *Microdictyon* was abundant at ROT-01 and ROT-02 in the east and southeast regions, occurring in 50% and 100% of sampled photoquadrats at these sites; but were absent from all other sites. The green algae *Caulerpa* and *Avrainvillea* were the next-most frequently recorded genera, occurring in 65.3% and 19.4% of sampled photoquadrats.

Turf algae, crustose coralline red algae, and cyanobacteria were all fairly common in 2007, occurring in 47.2%, 30.6%, and 54.2% of photoquadrats sampled at Rota. Turf algae were not recorded at ROT-01 in the east region; however, this functional group occurred in 25%–91.7% of photoquadrats sampled at the other sites surveyed at Rota. Recorded at all sites, cyanobacteria were ubiquitous and represented a prominent component of the algal community, occurring in 33.3%–75% of sampled photoquadrats.

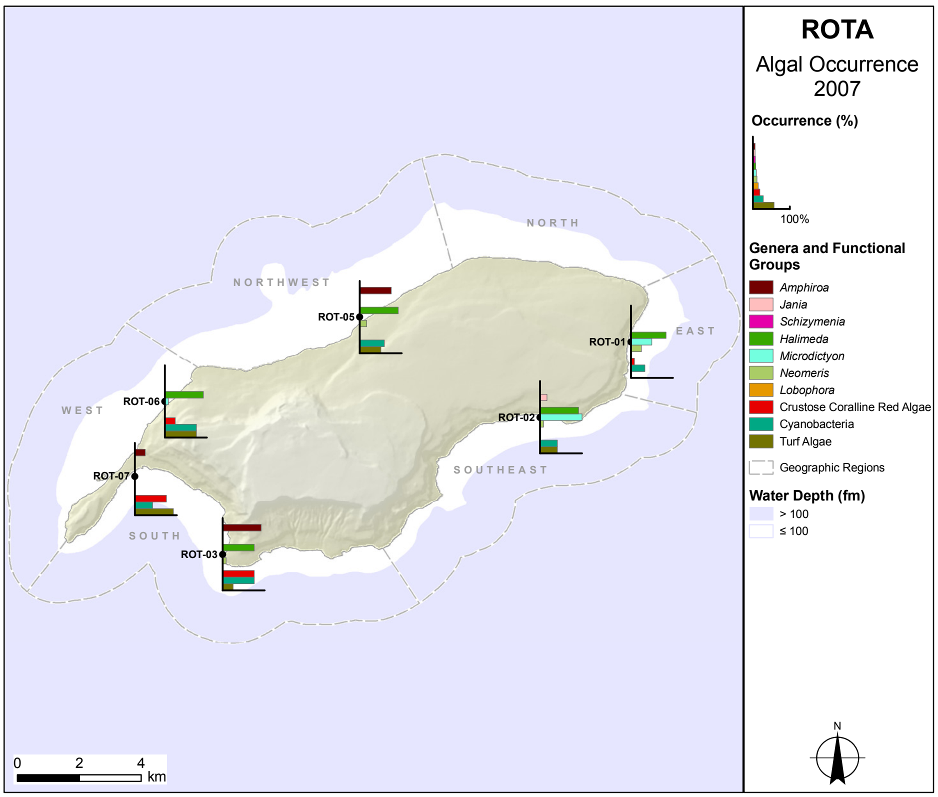
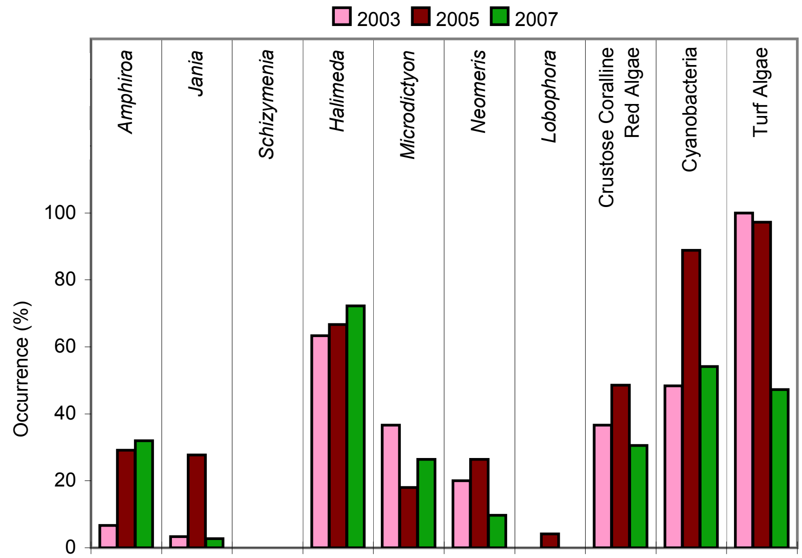



**Figure 5.6.1f.** Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys of forereef habitats at Rota during MARAMP 2007. Occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. The length of the x-axis denotes 100% occurrence.

The number of macroalgal genera recorded on forereef habitats at Rota was 22 and 23 during MARAMP 2003 and 2005 but decreased to 19 during MARAMP 2007. Such a small reduction in generic diversity is not enough to suggest environmental or benthic compositional change, since seasonal variability can affect greatly algal abundance and MARAMP 2007 took place during a different season than did MARAMP 2003 and 2005 (for information on data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys"). The overall occurrence of macroalgal genera did not fluctuate greatly between MARAMP survey periods. Species of the genus *Halimeda* consistently exhibited the highest occurrence during the 3 survey years, occurring in 63.3%–72.2% of sampled photoquadrats (Fig. 5.6.1g). The occurrence of species of the genus *Amphiroa* was low in 2003, when it was only recorded in 6.7% of sampled photoquadrats; however, it was found in 29.1% and 31.9% of sampled photoquadrats in 2005 and 2007. ROT-01 and ROT-02 remained dominated by green algae across MARAMP survey periods, and *Jania*, *Porteria*, and *Padina* were the only brown or red algal genera recorded at these sites.

Turf algae occurred in 100%, 97.2%, and 47.2% of photoquadrats sampled on forereef habitats at Rota during MARAMP 2003, 2005, and 2007. Observed occurrence of turf-algae declined by 50% between 2003 and 2007. Crustose coralline red algae occurred in 30.6%–48.6% of photoquadrats sampled across survey years, while cyanobacteria occurred in 48.3%–88.9% of sampled photoquadrats. No clear patterns of increasing or decreasing abundance of these functional groups were observed.

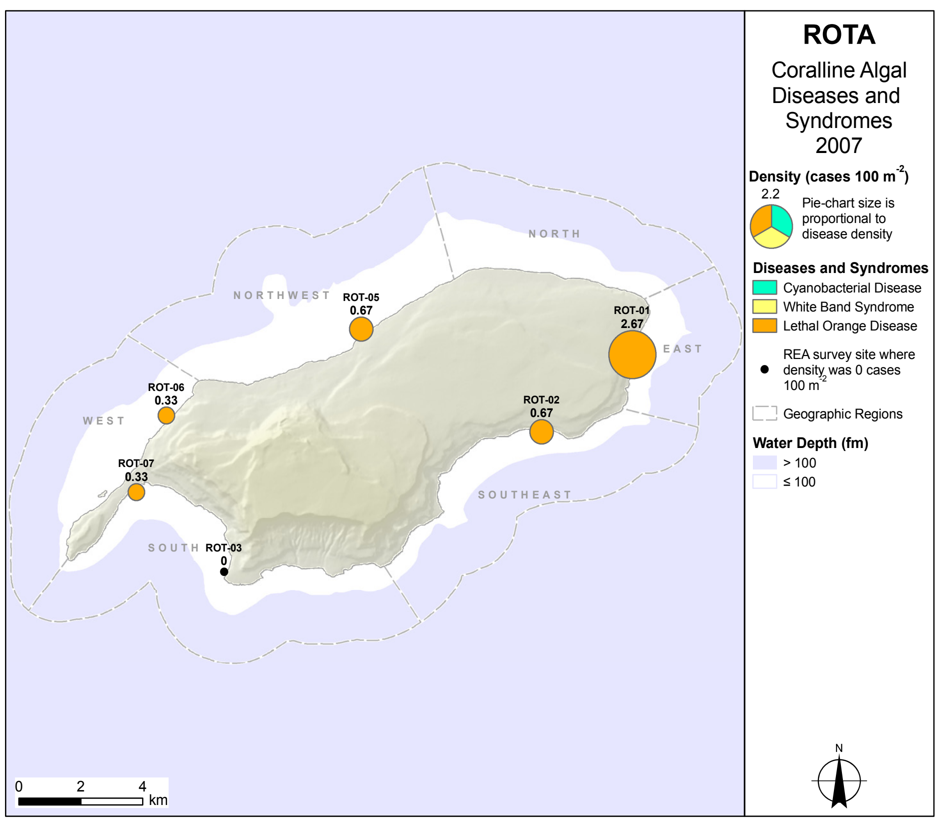
**Figure 5.6.1g.** Temporal comparison of occurrence (%) values from REA benthic surveys of algal genera and functional groups conducted on forereef habitats at Rota during MARAMP 2003, 2005, and 2007.




## 5.6.2 Surveys for Coralline-algal Disease

During MARAMP 2007, REA benthic surveys for coralline-algal disease were conducted in concert with coral-disease assessments at 6 sites on forereef habitat at Rota. These surveys covered a total reef area of more than 1700 m$^2$ and detected 13 cases. These numbers translate to an overall mean density of 0.8 cases 100 m$^{-2}$ (SE 0.4). Disease of coralline algae was found on reefs in all regions surveyed, although no disease was recorded at 1 of 2 sites surveyed in the south region, ROT-3 near Puntan Pona (Fig. 5.6.2a). Only 1 major type of coralline-algal disease was observed at Rota: coralline lethal orange disease, present at 5 of the 6 sites surveyed. The greatest density of 2.7 cases 100 m$^{-2}$ was found at ROT-01 in the east region. At ROT-02 and ROT-05 in the southeast and northwest regions, a much lower density of 0.7 cases 100 m$^{-2}$ was recorded.

**Figure 5.6.2a.** Densities (cases 100 m$^{-2}$) of coralline-algal diseases from REA benthic surveys conducted on forereef habitats at Rota during MARAMP 2007. The color-coded portions of the pie charts indicate disease-specific density.



## 5.7 Benthic Macroinvertebrates

### 5.7.1 Benthic Macroinvertebrates Surveys

Four groups of organisms—sea urchins, sea cucumbers, giant clams, and crown-of-thorn seastars (COTS)—were monitored on forereef habitats around the island of Rota through REA and towed-diver benthic surveys during MARAMP 2003, 2005, and 2007. This section describes by group the results of these surveys. A list of additional taxa observed during REA invertebrate surveys is provided in Chapter 3: "Archipelagic Comparisons."

Monitoring these 4 groups of ecologically and economically important taxa provides insight into the population distribution, community structure, and habitats of the coral reef ecosystems of the Mariana Archipelago. High densities of the corallivorous COTS can affect greatly the community structure of reef ecosystems. Giant clams are filter feeders that have been sought after in the Indo-Pacific for their meat, which is considered a delicacy, and for their shells. Sea cucumbers, sand-producing detritus foragers, are harvested for food. Sea urchins are important algal grazers and bioeroders.

In 2003, 5 REA surveys and 12 towed-diver benthic surveys were conducted, and in 2005, 6 REA surveys and 11 towed-diver benthic surveys were performed around Rota. In 2007, because of the lack of a scientific diver with expertise in invertebrates, no REA surveys were conducted; however, 10 towed-diver benthic surveys were completed. When considering survey results from towed-diver surveys, keep in mind that cryptic or small organisms can be difficult for divers to see, so the density values presented in this report, especially of giant clams and sea urchins, may under-represent the number of individuals present.

Minor fluctuations in observed macroinvertebrate densities on forereef habitats between MARAMP survey periods occurred with all target groups. Temporal patterns of islandwide mean macroinvertebrate density around Rota—from towed-diver benthic surveys during MARAMP 2003, 2005, and 2007—are shown later in this section (Figs. 5.7.1d, h, l, and p). Because of differences in survey methodology and in REA survey effort, with 5 surveys in 2003, 6 surveys in 2005, and no surveys in 2007, temporal comparisons of REA data are not presented (see Chapter 2: "Methods and Operational Background, Section 2.4.7: "Benthic Macroinvertebrates").

### *Giant Clams*

During MARAMP 2003, species of *Tridacna* giant clams were observed at 3 of the 5 REA sites surveyed and in 9 of the 12 towed-diver surveys conducted around Rota (Fig. 5.7.1a). The overall mean density of giant clams from REA surveys was 1.2 organisms 100 m$^{-2}$ (SE 0.58), and the islandwide mean density from towed-diver surveys was 0.03 organisms 100 m$^{-2}$ (SE 0.005). Results from REA surveys suggest that giant clams were most abundant at REA site ROT-03, near Puntan Pona with a mean density of 3 organisms 100 m$^{-2}$ (for place-names and their locations, see Figure 5.2a in Section 5.2: "Survey Effort"). Among all towed-diver surveys around Rota, the survey completed between Angyuta Island and Puntan Taipingot had the highest mean density of giant clams with 0.09 organisms 100 m$^{-2}$; segment densities from this survey ranged from 0 to 0.31 organisms 100 m$^{-2}$.

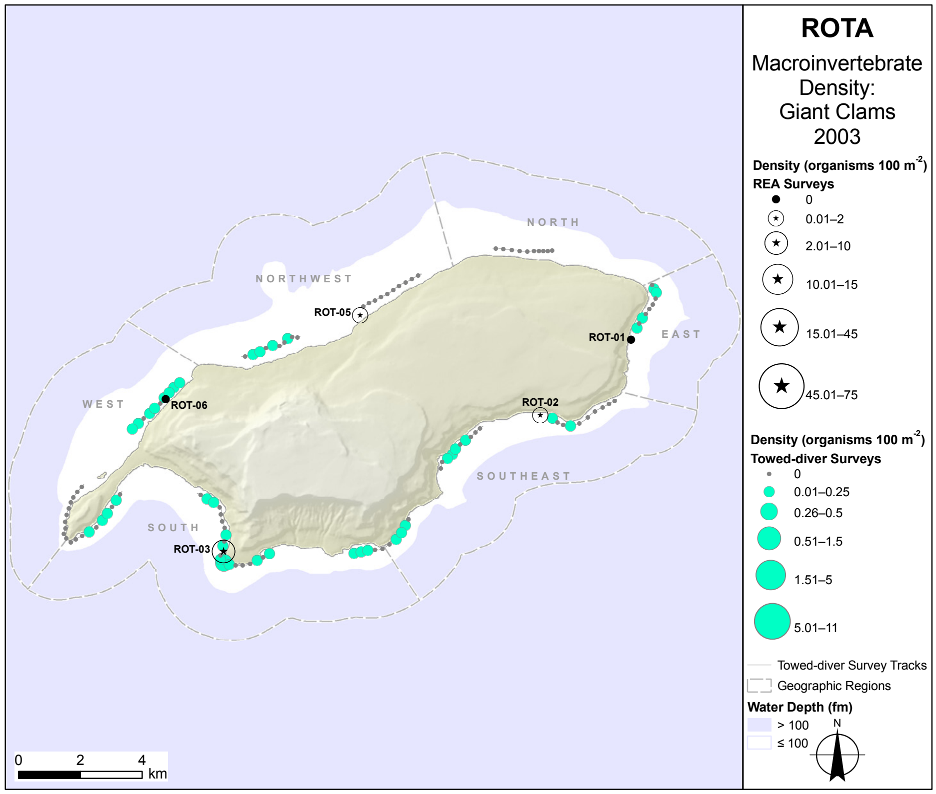



**Figure 5.7.1a.** Densities (organisms 100 m⁻²) of giant clams from REA and towed-diver benthic surveys of forereef habitats conducted around Rota during MARAMP 2003.

During MARAMP 2005, giant clams were observed at 1 of the 6 REA sites surveyed and in 7 of the 11 towed-diver surveys conducted at Rota (Fig. 5.7.1b). REA site ROT-07 had a density of 2 organisms 100 $m^{-2}$. The overall mean density of giant clams from towed-diver surveys was 0.01 organisms 100 $m^{-2}$ (SE 0.003). The towed-diver survey in the southeast region from Puntan As Fani past Puntan Sagua'gahga had the highest mean density of giant clams with 0.024 organisms 100 $m^{-2}$; segment densities from this survey ranged from 0 to 0.138 organisms 100 $m^{-2}$.

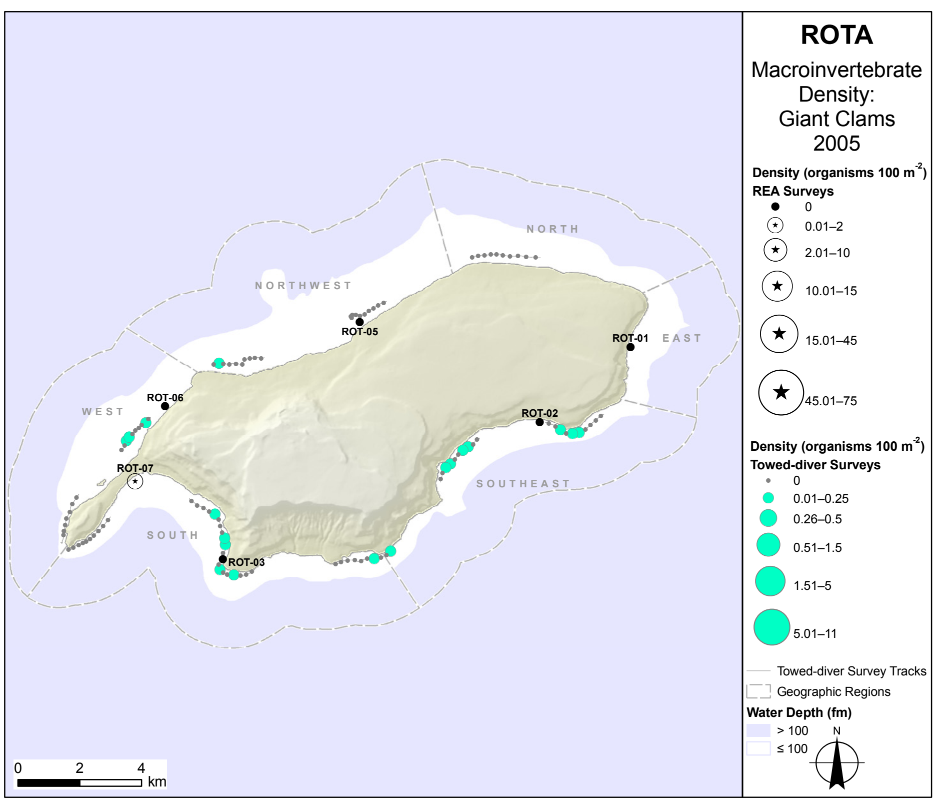



**Figure 5.7.1b.** Densities (organisms 100 $m^{-2}$) of giant clams from REA and towed-diver benthic surveys of forereef habitats conducted at Rota during MARAMP 2005

During MARAMP 2007, giant clams were observed in 6 of the 10 towed-diver surveys conducted at Rota (Fig. 5.7.1c) with an overall mean density of 0.008 organisms 100 m$^{-2}$ (SE 0.002). Among all towed-diver surveys at this island, the towed-diver survey completed between Afuefuniya Point and Puntan Malilok on the southern coast had the highest mean density of giant clams with 0.024 organisms 100 m$^{-2}$; segment densities from this survey ranged from 0 to 0.051 organisms 100 m$^{-2}$.

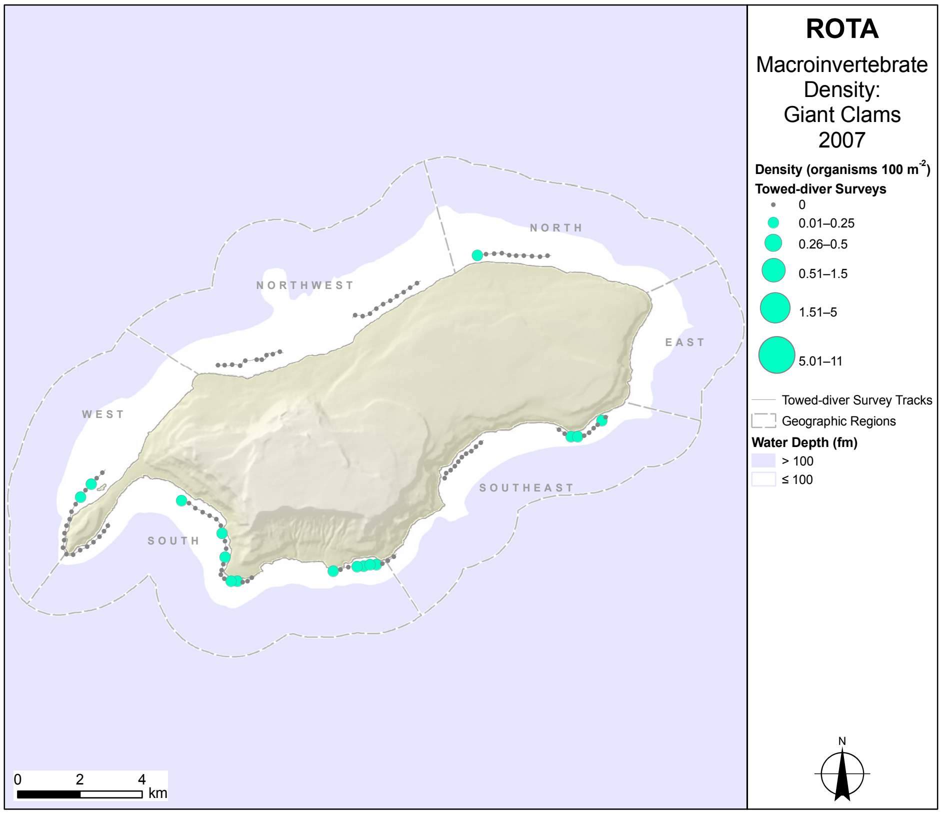



**Figure 5.7.1c.** Densities (organisms 100 m$^{-2}$) of giant clams from towed-diver benthic surveys of forereef habitats conducted at Rota during MARAMP 2007.

Towed-diver benthic surveys suggested low giant clam abundance at Rota during the 3 MARAMP survey periods, relative to the rest of the Mariana Archipelago. In the 3 survey years, densities of giant clams were low in the north and northwest regions. The overall observed mean density of giant clams was higher in 2003 than in 2005 and 2007 (Fig. 5.7.1d). Minor fluctuations in densities are not necessarily indicative of changes in the population structure of giant clams (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

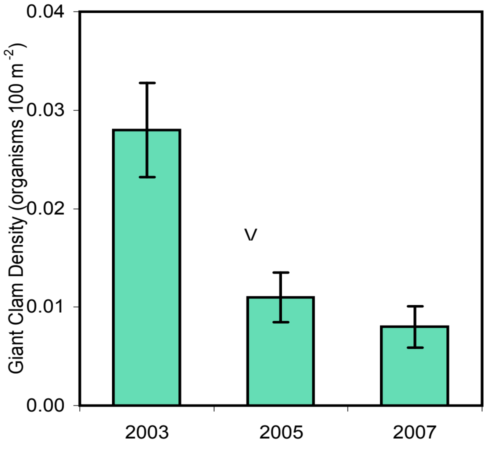


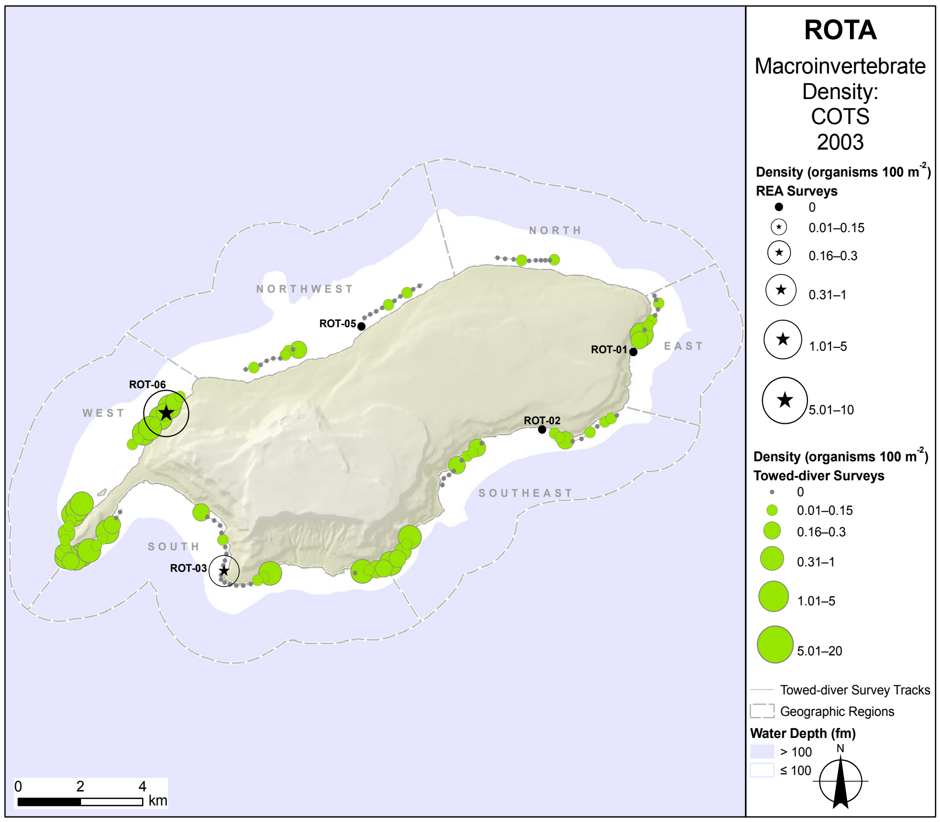

**Figure 5.7.1d.** Temporal comparison of mean densities (organisms 100 m$^{-2}$) of giant clams from towed-diver benthic surveys conducted on forereef habitats around Rota during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

### *Crown-of-thorns Seastars*

During MARAMP 2003, crown-of-thorn seastars (*Acanthaster planci*) were observed at 2 of the 5 REA sites surveyed and in all 12 towed-diver surveys conducted around Rota (Fig. 5.7.1e). The overall mean density from REA surveys was 1.4 organisms 100 $m^{-2}$ (SE 1.16), and the islandwide mean density from towed-diver surveys was 0.11 organisms 100 $m^{-2}$ (SE 0.01). Results from REA surveys suggest that COTS were most abundant at ROT-06 in the west region with 6 organisms 100 $m^{-2}$.

Among all towed-diver surveys around Rota in 2003, 4 surveys had mean densities of COTS > 0.20 organisms 100 $m^{-2}$. The towed-diver survey completed just south of Puntan Sailigai in the west region had the highest mean density of 0.25 organisms 100 $m^{-2}$; segment densities from this survey ranged from 0.08 to 0.47 organisms 100 $m^{-2}$. The 2 towed-diver surveys conducted around Puntan Taipingot had mean densities of 0.22 and 0.24 organisms 100 $m^{-2}$; segment densities for these 2 surveys ranged from 0 to 0.5 organisms 100 $m^{-2}$. The towed-diver survey around Puntan Malilok had a mean density of 0.23 organisms 100 $m^{-2}$; segment densities ranged from 0 to 0.55 organisms 100 $m^{-2}$.

**Figure 5.7.1e.** Densities (organisms 100 m⁻²) of COTS from REA and towed-diver benthic surveys of forereef habitats conducted around Rota during MARAMP 2003.




During MARAMP 2005, no COTS were observed at the 6 REA sites surveyed at Rota, but 9 of the 11 towed-diver surveys had recordings of COTS (Fig. 5.7.1f), with an overall mean density of 0.04 organisms 100 $m^{-2}$ (SE 0.01). Among all towed-diver surveys at Rota, the 2 towed-diver surveys completed in the south and west regions from Puntan Taipingot past Puntan Senhanom toward West Harbor had the greatest COTS density, each with 0.11 organisms 100 $m^{-2}$; segment densities from both surveys ranged from 0 to 0.26 organisms 100 $m^{-2}$.

During MARAMP 2007, COTS were observed in low densities in 5 of the 10 towed-diver surveys conducted at Rota (Fig. 5.7.1g), compared to estimates made at other islands, with an overall mean density of 0.11 organisms 100 $m^{-2}$ (SE 0.01). These 5 surveys were in the south, west, and northwest regions only. Among these 5 towed-diver surveys along the western half of Rota, the survey completed between Puntan Taipingot and West Harbor had the highest mean density with 0.034 organisms 100 $m^{-2}$; segment densities from this survey ranged from 0 to 0.09 organisms 100 $m^{-2}$.

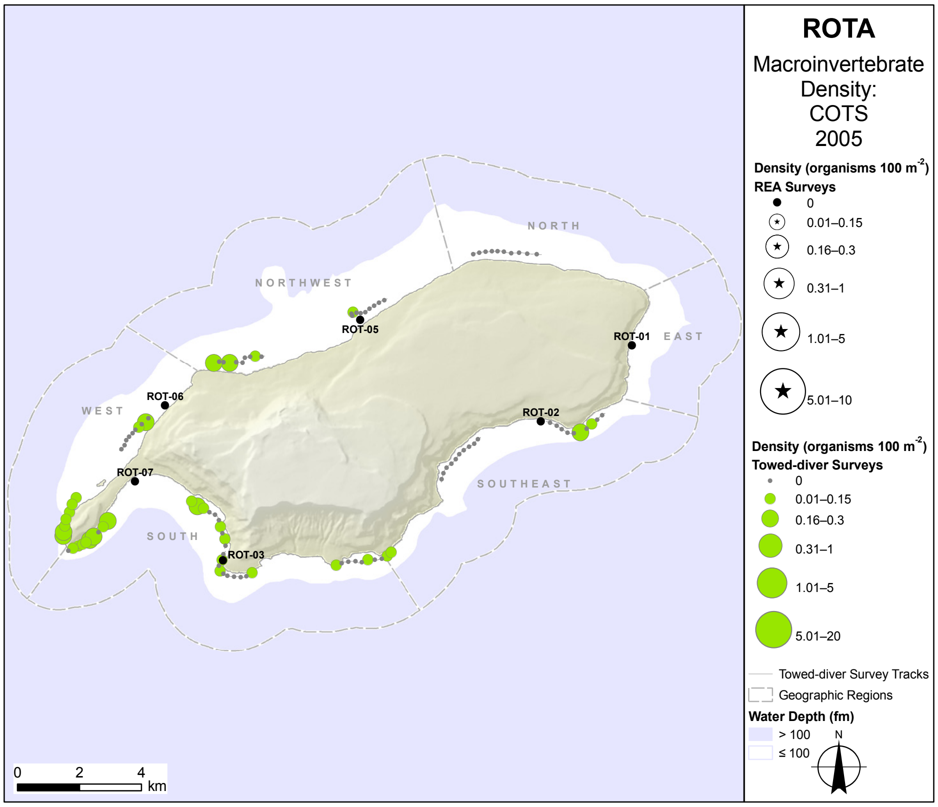



**Figure 5.7.1f.** Densities (organisms 100 $m^{-2}$) of COTS from REA and towed-diver benthic surveys of forereef habitats conducted at Rota during MARAMP 2005.

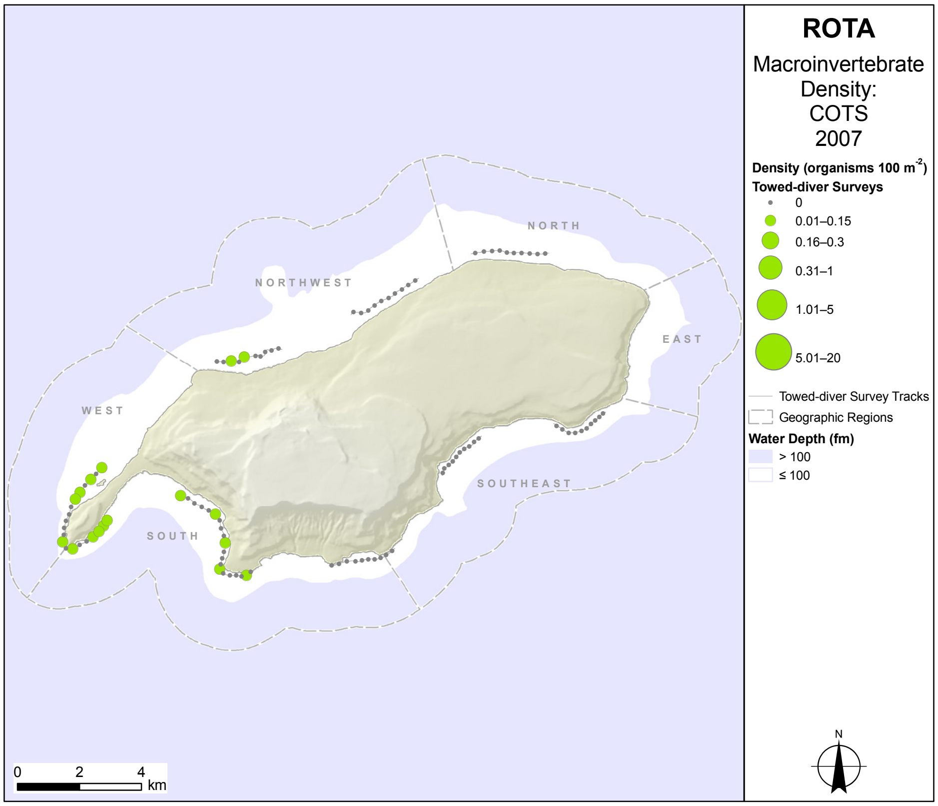



**Figure 5.7.1g.** Densities (organisms 100 $m^{-2}$) of COTS from towed-diver benthic surveys of forereef habitats conducted at Rota during MARAMP 2007.

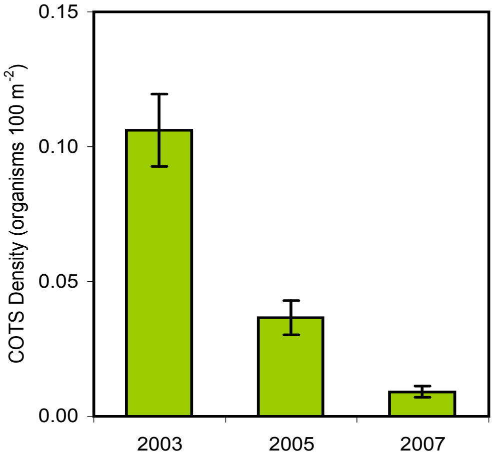


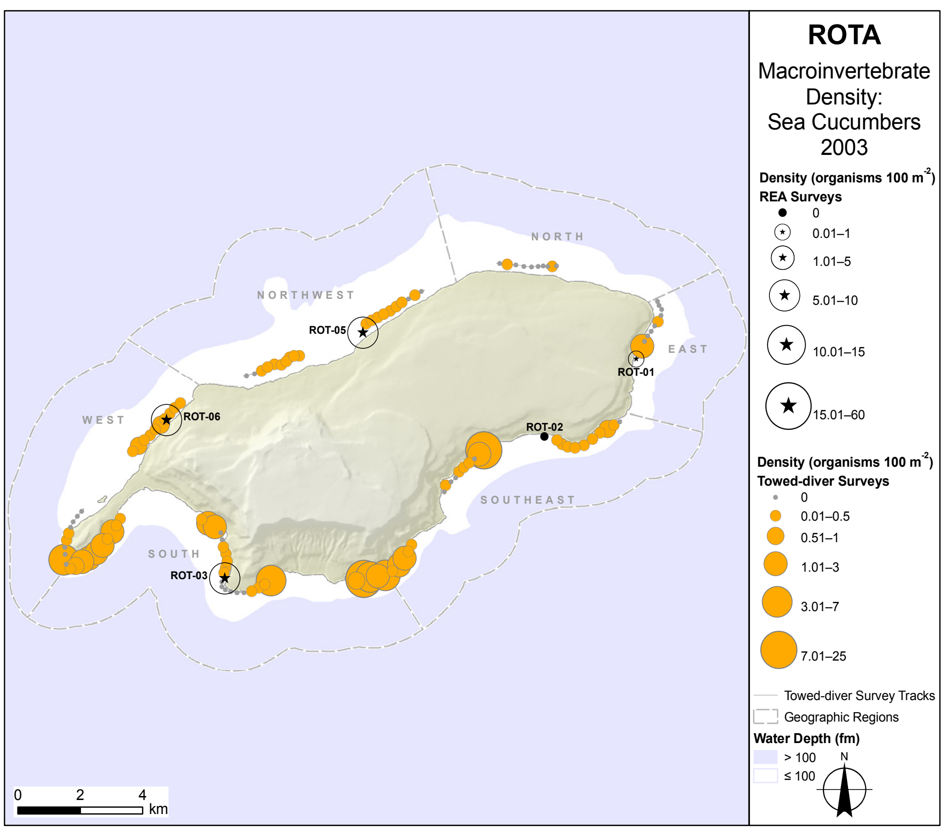

**Figure 5.7.1h.** Temporal comparison of COTS mean densities (organisms 100 m$^{-2}$) from towed-diver benthic surveys conducted on forereef habitats around Rota during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Towed-diver benthic surveys suggested relatively high daytime densities of COTS around Rota during MARAMP 2003, compared to the rest of the Mariana Archipelago, a sharp decline in 2005 and then again in 2007 (Fig. 5.7.1h). Given that these corallivorous seastars can decimate a reef, understanding whether their observed densities signify an outbreak is important. By means of a manta-tow technique—which uses snorkel divers as observers in a manner similar to the procedure established for using scuba divers to conduct MARAMP towed-diver surveys—Moran and De'ath (1992) defined a potential outbreak as a reef area where the density of *A. planci* was > 1500 organisms km$^{-2}$ (0.15 organisms 100 m$^{-2}$) and the level of dead coral present was at least 40%. Using this definition only in terms of density and considering each towed-diver survey as an individual reef area, localized areas with relatively high densities that suggest that they were undergoing an outbreak were found during MARAMP 2003: south of Puntan Sailigai, around Puntan Taipingot, and around Puntan Malilok with COTS densities of 0.25, 0.24, and 0.23 organisms 100 m$^{-2}$. By 2005, densities from Puntan Sailigai to Puntan Taipingot and around this island's peninsula toward East Harbor were still relatively high, although not above the aforementioned density criterion. Around the rest of Rota, COTS populations were substantially smaller in 2005 than in 2003. By 2007, these populations had dwindled. COTS density naturally fluctuates with food availability and variation in recruitment success (Birkeland and Lucas 1990; Fabricius et al. 2010; and Yamaguchi 1987).

### *Sea Cucumbers*

During MARAMP 2003, sea cucumbers were observed at 4 of the 5 REA sites surveyed and in all 12 towed-diver surveys conducted around Rota. The overall mean density of sea cucumbers from REA surveys was 4.6 organisms 100 m$^{-2}$

**Figure 5.7.1i.** Densities (organisms 100 m$^{-2}$) of sea cucumbers from REA and towed-diver benthic surveys of forereef habitats conducted around Rota during MARAMP 2003.



(SE 1.75), and the islandwide mean density from towed-diver surveys was 0.65 organisms 100 m$^{-2}$ (SE 0.18). Survey results suggest that sea cucumbers were most abundant at ROT-06 just south of Puntan Sailigai in the west region with 9 organisms 100 m$^{-2}$ (Fig. 5.7.1i). These sea cucumbers were from the genera *Holothuria, Stichopus*, and *Actinopyga.*

Among all towed-diver surveys around Rota, the survey completed just north of Puntan Ha`ina in the southeast region had the highest mean density with 2.19 organisms 100 m$^{-2}$; segment densities from this survey ranged from 0 to 18.88 organisms 100 m$^{-2}$. The second-greatest mean density of sea cucumbers from a towed-diver survey was 2.03 organisms 100 m$^{-2}$, recorded along the coast near Puntan Malilok at the border of the southeast and south regions; segment densities ranged from 0.08 to 8 organisms 100 m$^{-2}$.

During MARAMP 2005, sea cucumbers were observed at 3 of the 6 REA sites surveyed and in 10 of the 11 towed-diver surveys conducted at Rota. The sample mean density of sea cucumbers from REA sites was 0.5 organisms 100 m$^{-2}$ (SE 0.22), and the overall mean density from towed-diver surveys was 0.27 organisms 100 m$^{-2}$ (SE 0.05). Among all towed-diver surveys at Rota, the survey completed along the coast near Puntan Malilok in the south region had the highest mean density with 1.22 organisms 100 m$^{-2}$; segment densities from this survey ranged from 0 to 3.56 organisms 100 m$^{-2}$ (Fig. 5.7.1j).

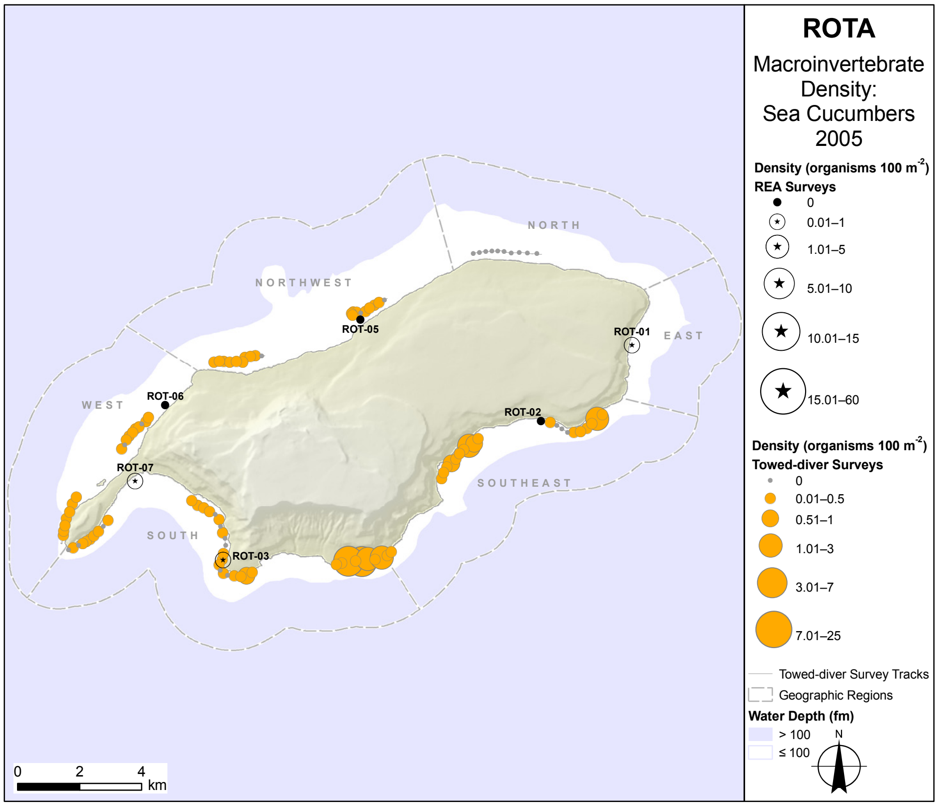
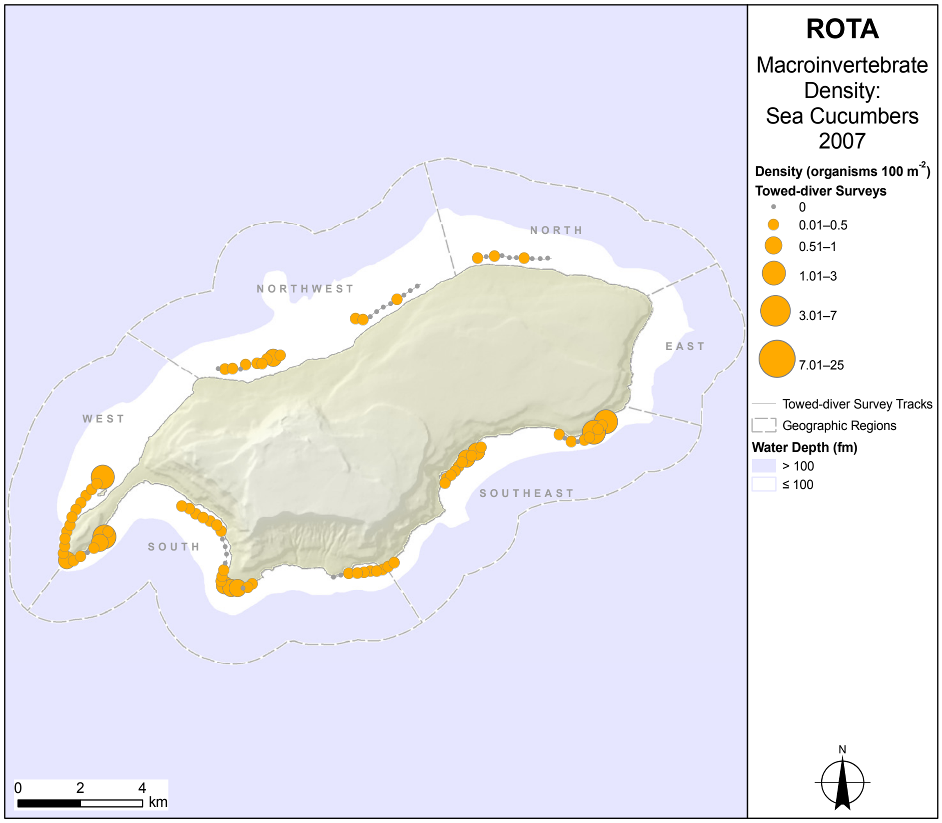



**Figure 5.7.1j.** Densities (organisms 100 m$^{-2}$) of sea cucumbers from REA and towed-diver benthic surveys of forereef habitats conducted at Rota during MARAMP 2005.

During MARAMP 2007, sea cucumbers were observed in all 10 towed-diver surveys conducted at Rota. The overall mean density of sea cucumbers from towed-diver surveys was 0.24 organisms 100 m$^{-2}$ (SE 0.04). Among all towed-diver surveys at Rota, the survey completed between Puntan Taipingot and West Harbor had the highest mean density with 0.45 organisms 100 m$^{-2}$; segment densities from this survey ranged from 0 to 1.77 organisms 100 m$^{-2}$ (Fig. 5.7.1k).

**Figure 5.7.1k.** Densities (organisms 100 $m^{-2}$) of sea cucumbers from REA and towed-diver benthic surveys of forereef habitats conducted at Rota during MARAMP 2007.



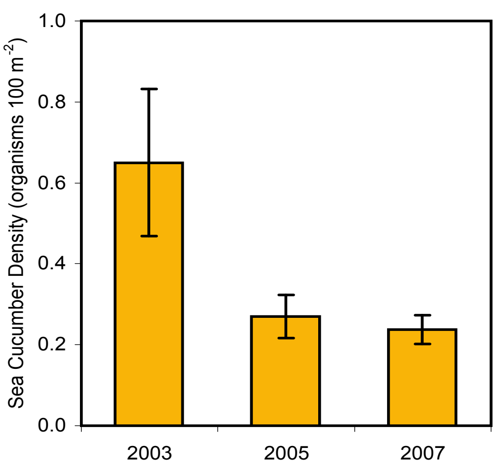




**Figure 5.7.1l.** Temporal comparison of mean densities (organisms 100 $m^{-2}$) of sea cucumbers from towed-diver benthic surveys conducted on forereef habitats around Rota during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Towed-diver surveys suggested higher daytime abundance of sea cucumbers in the south and southeast regions, relative to the other regions around Rota, during the 3 MARAMP survey periods. The overall observed mean density of sea cucumbers was higher in 2003 than in 2005 and 2007 (Fig. 5.7.1l). Minor fluctuations in densities are not necessarily indicative of changes in the population structure of sea cucumbers (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

### *Sea Urchins*

During MARAMP 2003, sea urchins were observed at all 5 REA sites surveyed and in 11 of the 12 towed-diver surveys conducted around Rota (Fig. 5.7.1m). The overall mean density of sea urchins from REA surveys was 165.4 organisms 100 $m^{-2}$ (SE 48.27), and the islandwide mean density from towed-diver surveys was 4.64 organisms 100 $m^{-2}$ (SE 0.55). Results from REA surveys suggest that ROT-06, just south of Puntan Sailigai in the west region, had the highest density of sea urchins with 309 organisms 100 $m^{-2}$. All sea urchins observed at this site were from the genus *Echinostephus*. The second-greatest density of 243 organisms 100 $m^{-2}$ was recorded in the east region at ROT-01, where the rock-boring urchin *Echinostrephus* was again the dominant urchin genus at this site, accounting for 82% of recorded urchins. Sea urchins from the genera *Echinometra* and *Echinothrix* were also present at both sites, accounting for 4% and 14% of sea urchins recorded.

Among all towed-diver surveys around Rota in 2003, the survey completed in the southeast region in Aratsu-wan had the highest mean density of sea urchins with 11.53 organisms 100 $m^{-2}$; segment densities from this survey ranged from 3.66 to 18.90 organisms 100 $m^{-2}$. The second-greatest mean density of sea urchins was 9.46 organisms 100 $m^{-2}$, recorded just south of Puntan Sailigai in the west region; segment densities ranged from 0 to 30.52 organisms 100 $m^{-2}$.

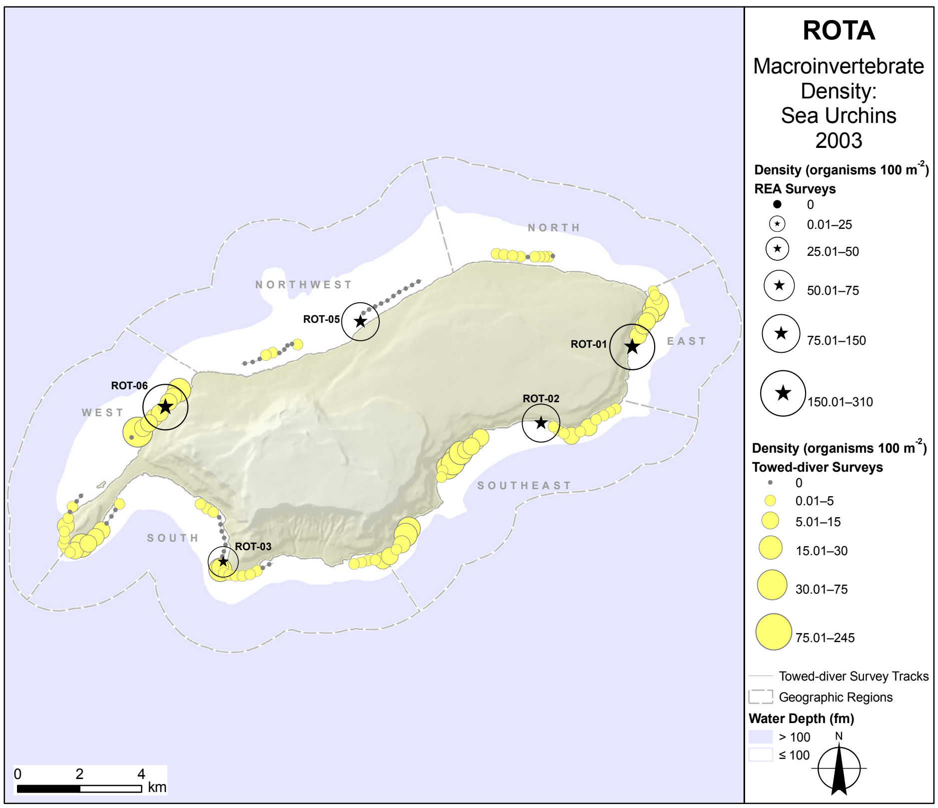



**Figure 5.7.1m.** Densities (organisms 100 $m^{-2}$) of sea urchins from REA and towed-diver benthic surveys of forereef habitats conducted around Rota during MARAMP 2003.

During MARAMP 2005, sea urchins were observed at 2 of the 6 REA sites surveyed and in 10 of the 11 towed-diver surveys conducted at Rota (Fig. 5.7.1n). The sample mean density of sea urchins from REA surveys was 7.16 organisms 100 $m^{-2}$ (SE 6.77), and the overall mean density from towed-diver surveys was 6.8 organisms 100 $m^{-2}$ (SE 1.14). Among all towed-diver surveys at Rota, the survey completed south of Angyuta Island to Puntan Taipingot in the south region had the greatest mean density with 18.43 organisms 100 $m^{-2}$; segment densities from this survey ranged from 3.17 to 38.68 organisms 100 $m^{-2}$. The second-greatest mean density of sea urchins was 13.79 organisms 100 $m^{-2}$, recorded between Puntans As Fani and Sagua`gahga in the southeast region; segment densities ranged from 0 to 50.17 organisms 100 $m^{-2}$.

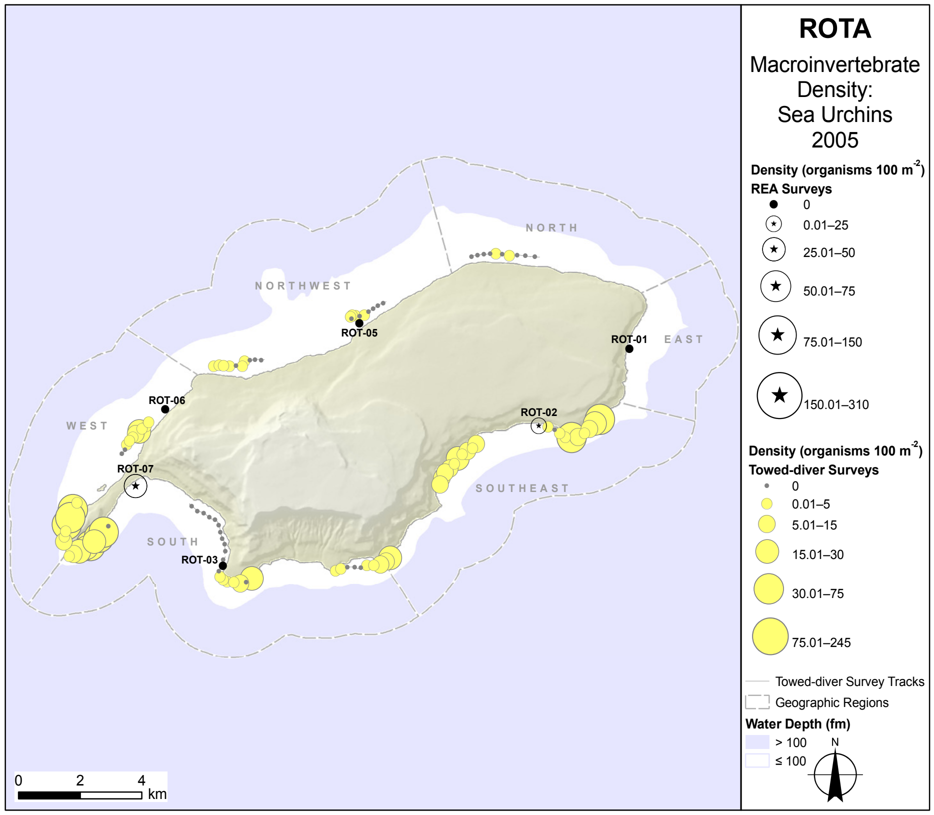



**Figure 5.7.1n.** Densities (organisms 100 m$^{-2}$) of sea urchins from REA and towed-diver benthic surveys of forereef habitats conducted at Rota during MARAMP 2005.

During MARAMP 2007, sea urchins were observed in 8 of the 10 towed-diver surveys conducted at Rota (Fig. 5.7.1o) with an overall mean density of 4.79 organisms 100 m$^{-2}$ (SE 0.70). Among all towed-diver surveys at this island, the survey conducted south of Angyuta Island to Puntan Taipingot in the south region had the highest mean density with

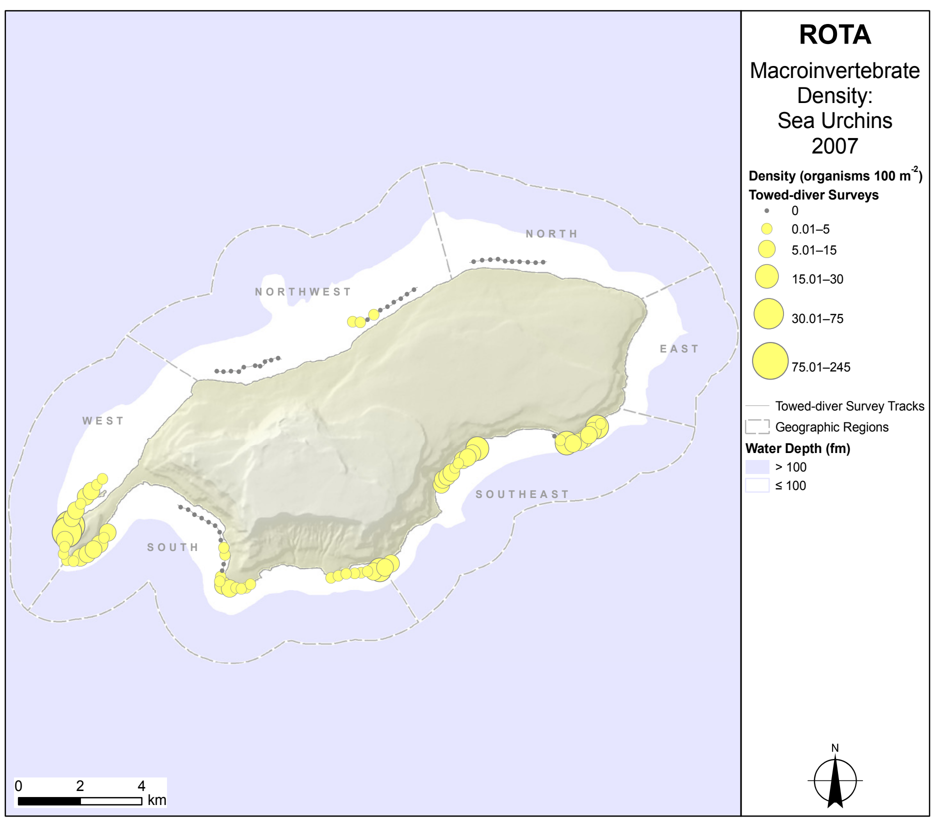



**Figure 5.7.1o.** Densities (organisms 100 m$^{-2}$) of sea urchins from towed-diver benthic surveys of forereef habitats conducted at Rota during MARAMP 2007.

14.07 organisms 100 m$^{-2}$; segment densities from this survey ranged from 2.91 to 43.28 organisms 100 m$^{-2}$.

The overall observed mean density of sea urchins was slightly higher in 2005 than in 2003 and 2007 (Fig. 5.7.1p). Minor fluctuations in densities are not necessarily indicative of changes in the population structure of sea urchins (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

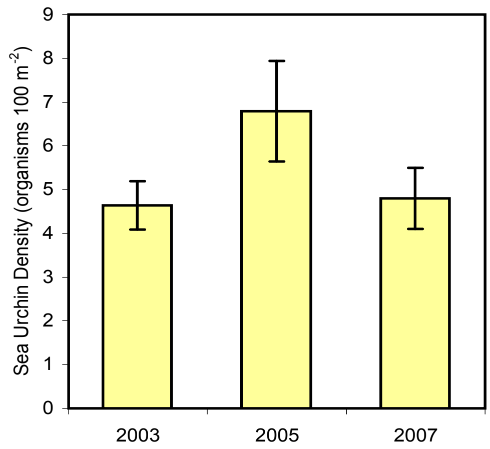



**Figure 5.7.1p.** Temporal comparison of mean densities (organisms 100 m$^{-2}$) of sea urchins from towed-diver benthic surveys conducted on forereef habitats around Rota during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

## 5.8 Reef Fishes

### 5.8.1 Reef Fish Surveys

#### *Large-fish Biomass*

During MARAMP 2003, 12 towed-diver surveys for large fishes (≥ 50 cm in total length [TL]) were conducted in forereef habitats around the island of Rota. The islandwide estimated mean biomass of large fishes, calculated as weight per unit area, was 0.49 kg 100 m$^{-2}$ (SE 0.14). Observed biomass values for large fishes were highest in the southwest region, where

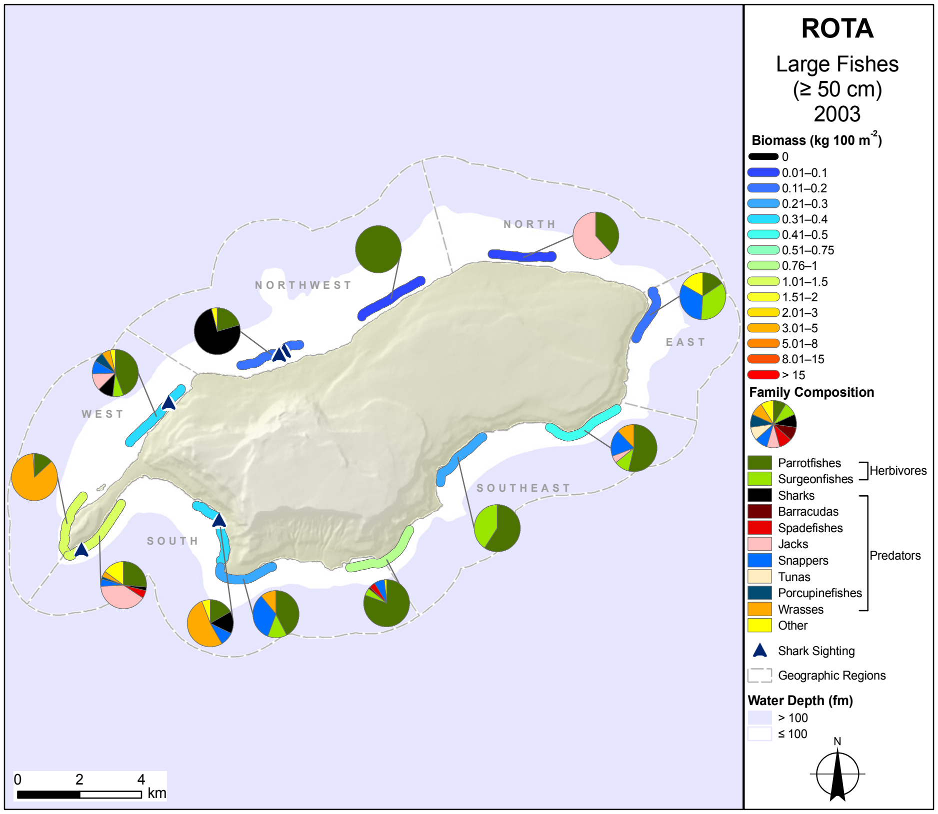



**Figure 5.8.1a.** Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m$^{-2}$), family composition, and individual shark sightings from towed-diver fish surveys of forereef habitats conducted around Rota during MARAMP 2003. Each blue triangle represents a sighting of one or more sharks recorded inside or outside the survey area over which it is shown.

a school of bigeye trevally (*Caranx sexfaciatus*) and multiple humphead wrasse (*Cheilinus undulatus*) were observed (Fig. 5.8.1a). Parrotfishes (Scaridae) and wrasses (Labridae) together accounted for 63% of the overall mean biomass of large fishes. Parrotfishes accounted for the greatest proportion of large-fish biomass, with the filament-finned parrotfish (*Scarus altipinnis*) contributing 38% of parrotfish biomass. The humphead wrasse accounted for the majority of wrasse biomass with 12 individuals observed in 2003. Jacks (Carangidae) were also common, contributing 11% of islandwide large-fish biomass. The bigeye trevally contributed 0.05 kg 100 m$^{-2}$ to overall large-fish biomass and accounted for 84% of jack biomass. Five reef sharks (Carcharhinidae) were observed around Rota: 3 blacktip reef shark (*Carcharhinus melanopterus*) and 2 whitetip reef shark (*Triaenodon obesus*).

During MARAMP 2005, 11 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats at Rota. The overall estimated mean biomass of large fishes at this island was 0.48 kg 100 m$^{-2}$ (SE 0.23). Observed biomass values for large fishes were highest in the west region, where a large school of blackfin barracuda (*Sphyraena qenie*) was observed (Fig. 5.8.1b). Barracudas (Sphyraenidae) and wrasses made up the majority of the overall biomass, together accounting for 56% or 0.27 kg 100 m$^{-2}$ of the overall mean large-fish biomass. The blackfin barracuda was the most abundant barracuda species, accounting for 24% of overall biomass of large fishes. Consistent with observations made in 2003, the humphead wrasse was the dominant wrasse species by weight with 8 individuals recorded. Batfishes (Ephippidae) and parrotfishes were also common, and the teira batfish (*Platax teira*) and ember parrotfish (*Scarus rubroviolaceus*) were the most abundant batfish and parrotfish species, contributing 0.06 kg 100 m$^{-2}$ and 0.02 kg 100 m$^{-2}$ to overall large-fish biomass. Two reef sharks were observed at Rota: 1 whitetip reef shark and 1 blacktip reef shark.

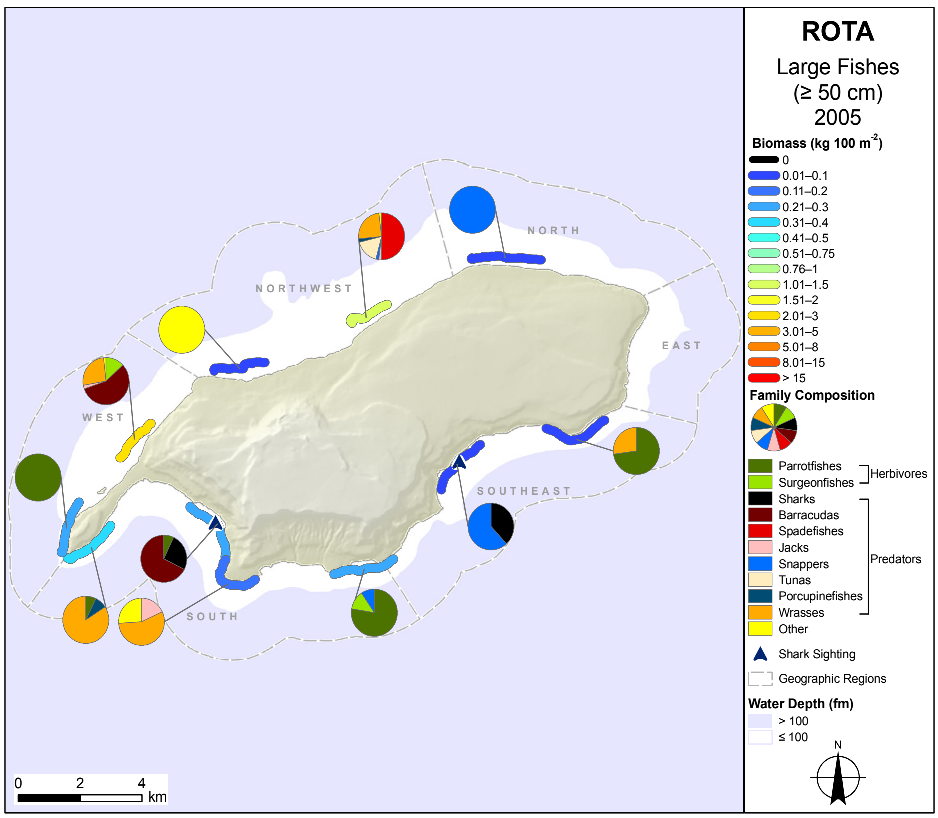



**Figure 5.8.1b.** Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m$^{-2}$), family composition, and individual shark sightings from towed-diver fish surveys of forereef habitats conducted at Rota during MARAMP 2005. Each blue triangle represents a sighting of one or more sharks recorded inside or outside the survey area over which it is shown.

During MARAMP 2007, 10 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats at Rota. The overall estimated mean biomass of large fishes at this island was 0.14 kg 100 m$^{-2}$ (SE 0.05), lower than biomass estimates made in 2005 and 2003. Observed biomass values for large fishes were highest in the south region, where dogtooth tuna (*Gymnosarda unicolor*) and surgeonfishes (Acanthuridae) were common (Fig. 5.8.1c). Surgeonfishes and tunas (Scombridae) together contributed 32% or 0.03 kg 100 m$^{-2}$ of overall large-fish biomass. The bulbnose unicornfish (*Naso tonganus*) dominated surgeonfish biomass and accounted for 10% of the overall mean biomass of large fishes. Dogtooth tuna was the most abundant tuna species, contributing 11% of overall large-fish biomass. A single whitetip reef shark was observed at Rota, but, unlike in 2003 and 2005, no humphead wrasse were recorded.

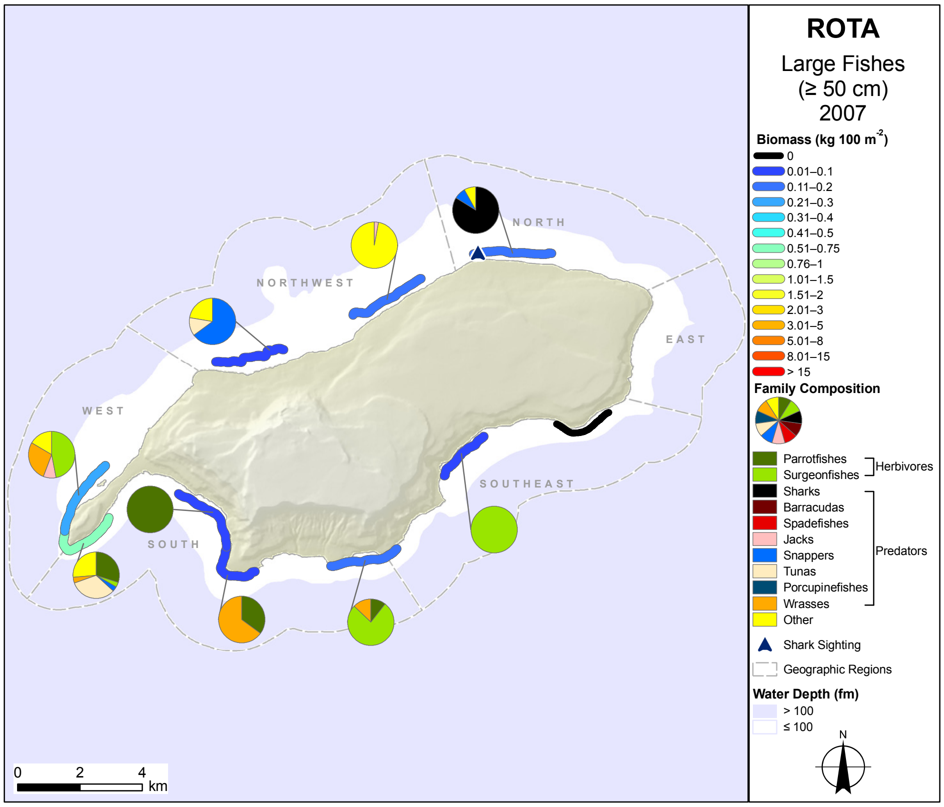



**Figure 5.8.1c.** Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m$^{-2}$), family composition, and individual shark sightings from towed-diver fish surveys of forereef habitats conducted at Rota during MARAMP 2007. Each blue triangle represents a shark sighting of one or more sharks recorded inside or outside of the survey area over which it is shown.

Overall large-fish biomass from towed-diver surveys of forereef habitats at Rota was moderately low in 2003 and 2005, compared to the rest of the Mariana Archipelago, and was lower still in 2007 (Fig. 5.8.1d). No single species consistently dominated large-fish biomass, and no consistent spatial pattern was observed during the 3 MARAMP survey periods. One observation that stands out is the sighting in 2003 of a large school of bigeye trevally in the southwest region. Also notable were sightings of humphead wrasse with 12 individuals observed in 2003, 8 individuals seen in 2005, and none recorded in 2007.

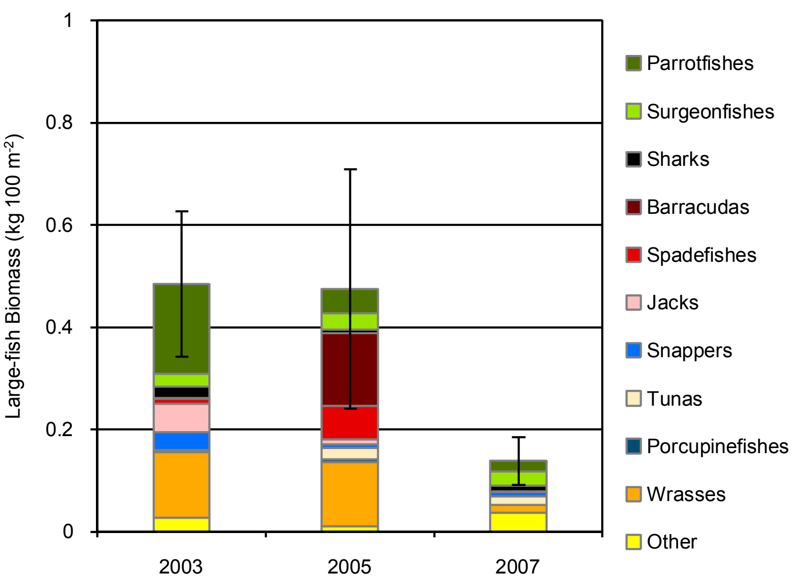


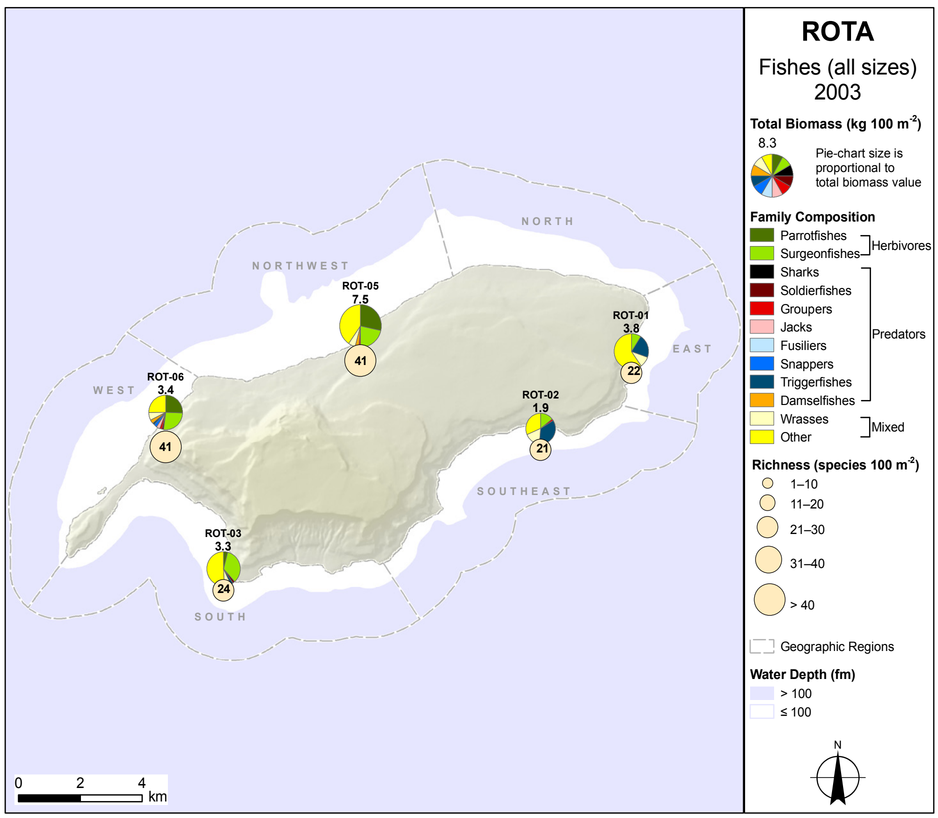

**Figure 5.8.1d.** Temporal comparison of mean values of large-fish (≥ 50 cm in TL) biomass (kg 100 m$^{-2}$) from towed-diver fish surveys of forereef habitats conducted around Rota during MARAMP 2003, 2005 and 2007. Error bars indicate standard error (± 1 SE) of the mean.

### *Total Fish Biomass and Species Richness*

Total fish biomass for the 5 REA sites surveyed using belt transects in forereef habitats at Rota during MARAMP 2003 was moderately low compared to other sites in the Mariana Archipelago with an overall sample mean of 4.00 kg 100 m$^{-2}$ (SE 0.93). The highest mean biomass of 7.49 kg 100 m$^{-2}$ was observed at ROT-05 in the northwest region, and the lowest biomass of 1.95 kg 100 m$^{-2}$ was found at ROT-02 in the southeast region (Fig. 5.8.1e). Emperors (Lethrinidae) and surgeonfishes were the dominant families in terms of biomass, contributing 30% (1.21 kg 100 m$^{-2}$) and 21% (0.85 kg 100 m$^{-2}$) of overall total fish biomass. The striped large-eye bream (*Gnathodentex aureolineatus*) was the major emperor species, accounting for 40% of emperor biomass, while the orangespot surgeonfish (*Acanthurus olivaceus*) was the major surgeonfish species, contributing 37% of surgeonfish biomass. No reef sharks were observed during these site-specific fish surveys.

Based on REA surveys conducted during MARAMP 2003, species richness at Rota ranged from 21 to 41 species 100 m$^{-2}$. The highest species richness was found at both ROT-06 in the west region and ROT-05 in the northwest region. Wrasses were the most diverse family with 23 species recorded at Rota in 2003. The fivestripe wrasse (*Thalassoma quinquevittatum*) and the blunthead wrasse (*Thalassoma amblycephalum*) were the most abundant wrasse species. Triggerfishes (Balistidae) were the most abundant fish taxa overall, and the redtoothed triggerfish (*Odonus niger*) dominated counts with 179 individuals 100 m$^{-2}$ observed. All of these triggerfishes were < 10 cm in TL; hence, they likely were very recently recruited.

**Figure 5.8.1e.** Observations of total fish biomass (all species and size classes in kg 100 m$^{-2}$), family composition, and species richness (species 100 m$^{-2}$) from REA fish surveys using the belt-transect method in forereef habitats at Rota during MARAMP 2003.




Mean total fish biomass for the 6 REA sites surveyed in forereef habitats at Rota during MARAMP 2005 was 5.73 kg 100 m$^{-2}$ (SE 1.54). The highest fish biomass of 12.64 kg 100 m$^{-2}$ was observed at ROT-02 in the southeast region (Fig. 5.8.1f), and the lowest fish biomass of 2.62 kg 100 m$^{-2}$ was found at ROT-05 in the northwest region. Surgeonfishes accounted for the largest proportion of (39%) or 2.25 kg 100 m$^{-2}$ of total fish biomass for Rota. Consistent with the observations made in 2003, the orangespot surgeonfish was the major surgeonfish species, contributing 35% or 0.80 kg 100 m$^{-2}$ of surgeonfish biomass. Parrotfishes contributed 19% of the overall total fish biomass. The bullethead parrotfish (*Chlorurus sordidus*) accounted for 61% or 0.65 kg 100 m$^{-2}$ of parrotfish biomass. No sharks were observed during these site-specific fish surveys.

Based on REA surveys conducted during MARAMP 2005, species richness at Rota was heterogeneous among REA sites with a range of 16–38 fish species 100 m$^{-2}$. The highest species richness was observed at ROT-03 in the south region near Puntan Pona in the Sasanhaya Fish Reserve. Wrasses and surgeonfishes were the 2 most diverse families with 29 and 20

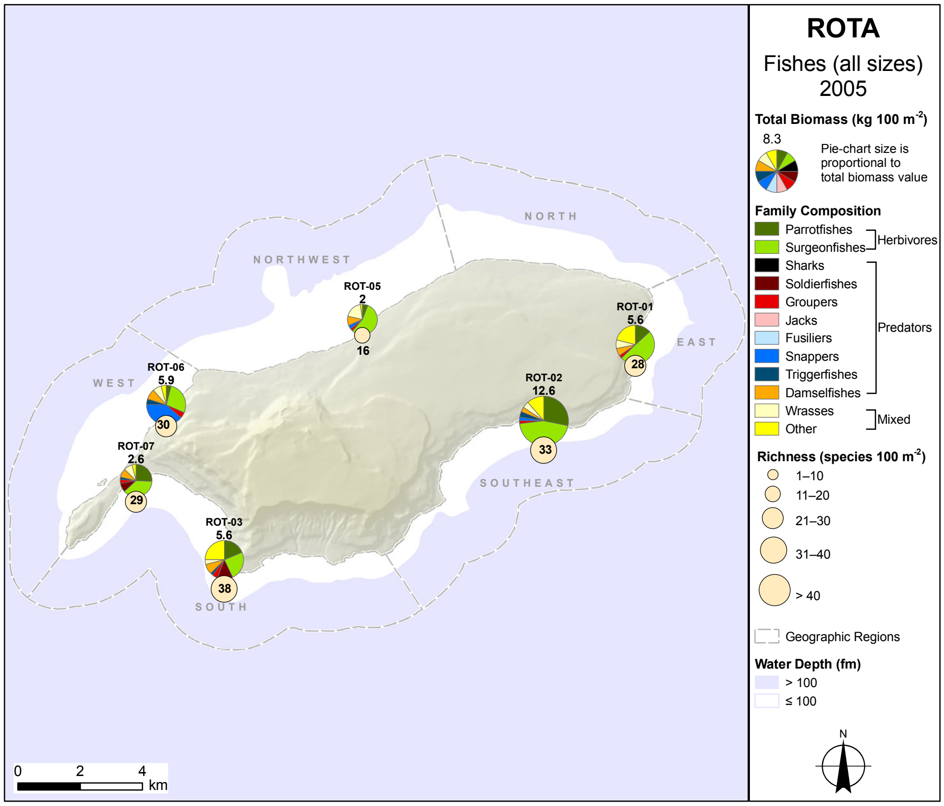



**Figure 5.8.1f.** Observations of total fish biomass (all species and size classes in kg 100 m$^{-2}$), family composition, and species richness (species 100 m$^{-2}$) from REA fish surveys using the belt-transect method in forereef habitats at Rota during MARAMP 2005

species recorded. The ornate wrasse (*Halichoeres ornatissimus*) was the most abundant wrasse species, and the brown surgeonfish (*Acanthurus nigrofuscus*) was the most abundant surgeonfish species. Damselfishes (Pomacentridae) were the most abundant fish taxa overall, and the midget chromis (*Chromis acares*) was the most common species with 44 individuals 100 m$^{-2}$ observed.

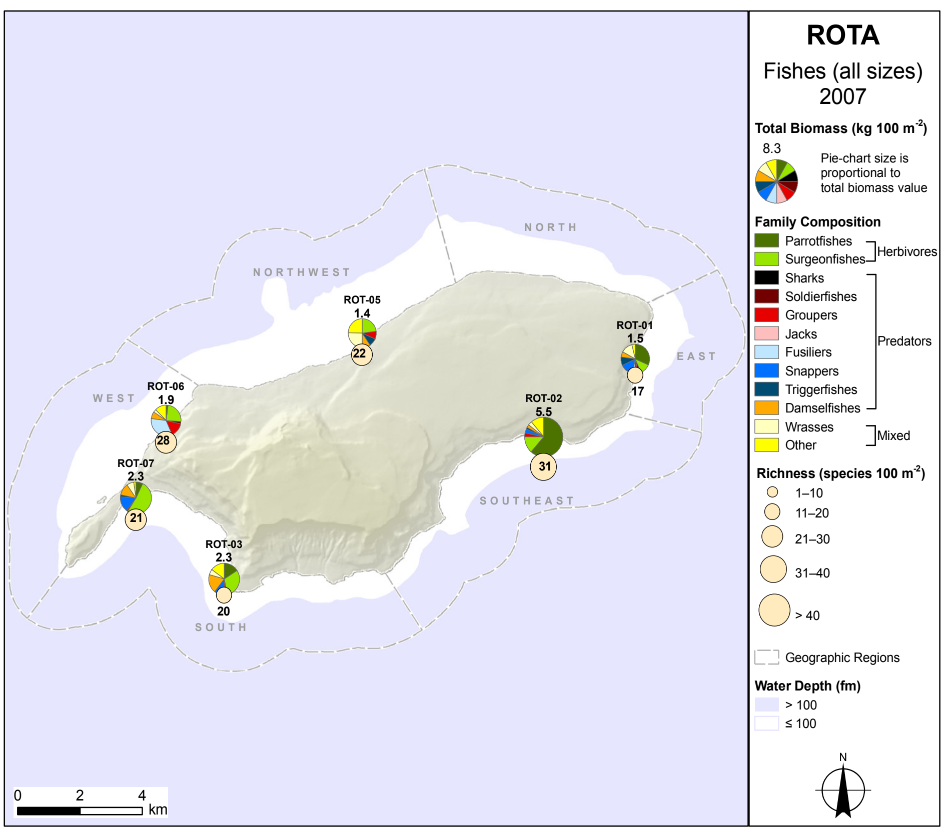
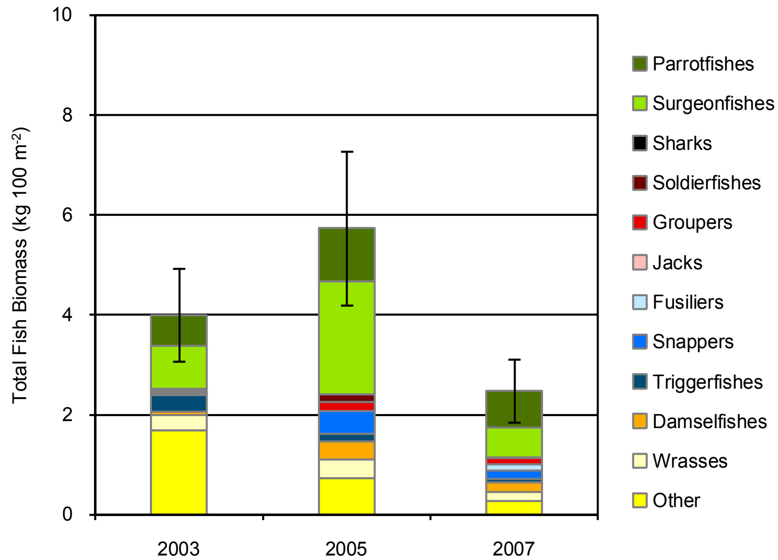



**Figure 5.8.1g.** Observations of total fish biomass (all species and size classes in kg 100 m$^{-2}$), family composition, and species richness (species 100 m$^{-2}$) from REA fish surveys using the belt-transect method in forereef habitats at Rota during MARAMP 2007.

Total fish biomass for the 6 REA sites surveyed in forereef habitats at Rota during MARAMP 2007 was low, compared to other sites in the Mariana Archipelago, with an overall sample mean of 2.48 kg 100 m$^{-2}$ (SE 0.63). The highest biomass of 5.93 kg 100 m$^{-2}$ was observed at ROT-02 in the southeast region (Fig. 5.8.1g). Parrotfishes accounted for the largest proportion (30%) or 0.74 kg 100 m$^{-2}$ of overall total fish biomass. Surgeonfishes were the second-most dominant family, contributing 24% of total fish biomass for Rota. The bullethead parrotfish was the major parrotfish species by weight, and the striated surgeonfish (*Ctenochaetus striatus*) was the major surgeonfish species by weight. No sharks were observed during these site-specific fish surveys.

Based on REA surveys conducted during MARAMP 2007, species richness at Rota ranged from 17 to 31 species 100 m$^{-2}$. The highest species richness was observed at ROT-02 in the southeast region (Fig. 5.8.1g). Wrasses, surgeonfishes, and damselfishes were the 3 most diverse families with 29, 15, and 15 species recorded, respectively. The red-lined wrasse (*Halichoeres biocellatus*) was the most abundant wrasse species, and the brown surgeonfish was the most abundant surgeonfish species. Damselfishes again were the most abundant fish taxa overall, and the ocellate damselfish (*Pomacentrus vaiuli*) was the most common species with more than 20 individuals 100 m$^{-2}$ recorded at Rota.

**Figure 5.8.1h.** Temporal comparison of mean values of total fish biomass (all species and size classes in kg 100 m$^{-2}$) from REA fish surveys of forereef habitats conducted at Rota during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.




No persistent spatial pattern was observed for total fish biomass in forereef habitats at Rota between the 3 MARAMP survey periods; however, the highest mean value of total fish biomass was found at ROT-02 in the southeast region in both 2003 and 2005. Across the 3 MARAMP survey years combined, the overall mean total fish biomass for Rota was 4.07 kg 100 m$^{-2}$ (Fig. 5.8.1h), a low value relative to the rest of the Mariana Archipelago. The highest fish biomass of 12.64 kg 100 m$^{-2}$ was recorded at ROT-02 in 2005, and the lowest fish biomass of 1.37 kg 100 m$^{-2}$ was observed at ROT-05 in the northwest region in 2007. No single species accounted for the greatest proportion of total fish biomass for the 3 survey periods; however, surgeonfishes were one of the 2 the most dominant families in each year, accounting for 21%–39% of overall total fish biomass. The orangespot surgeonfish, brown surgeonfish, and striated surgeonfish collectively made up more than 50% of surgeonfish biomass recorded in 2003, 2005, and 2007. No sharks were observed in sight-specific surveys during any of the 3 MARAMP survey periods.

Species richness at Rota was recorded within a range of 23.3–29.7 species 100 m$^{-2}$ during the 3 MARAMP survey years, with no clear spatial pattern observed. Wrasses, surgeonfishes, and damselfishes were the 3 most diverse families overall, with an average of 27, 16, and 14 species recorded. Damselfishes were the most abundant taxa of fishes; however, no single species consistently dominated counts in the 3 MARAMP survey periods.

## 5.9 Marine Debris

### 5.9.1 Marine Debris Surveys

During MARAMP 2003, 3 sightings of derelict fishing gear and 2 sightings of wrecks were recorded in the 12 towed-diver surveys conducted on forereef habitats around the island of Rota (Fig. 5.9.1a). The 2 wreck sightings, which included a propeller, blade, anchor, and chain, were made in the south region and were probably 2 of 5 known wrecks in Sasanhaya Bay in the south region (for place-names and their locations, see Figure 5.2a in Section 5.2: "Survey Effort"): 3 wooden Japanese subchasers were sunk during or after WWII, and 2 steel Chinese smuggling ships were impounded and sunk intentionally in 1999 as artificial dive sites. Two fishing lines were recorded, 1 in the south region and 1 in the west region. The third sighting of derelict fishing gear was noted in the northwest region, but no additional descriptive information was recorded. No munitions or other man-made objects were identified.

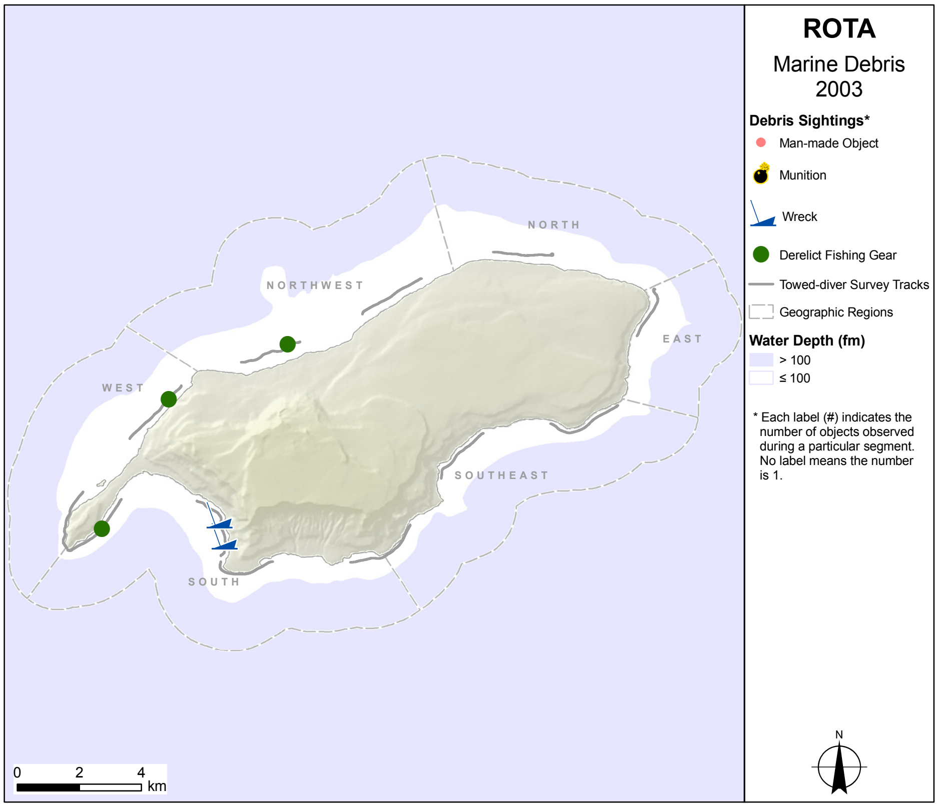
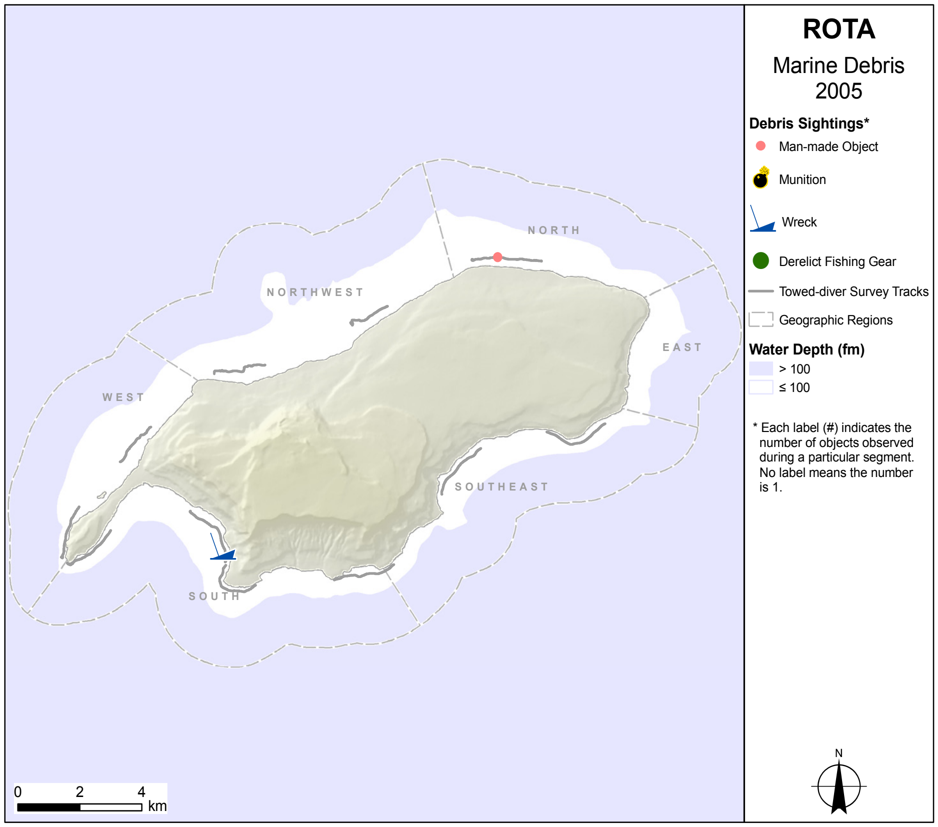



**Figure 5.9.1a.** Qualitative observations of marine debris from towed-diver benthic surveys of forereef habitats conducted around Rota during MARAMP 2003. Symbols indicate the presence of specific debris types.

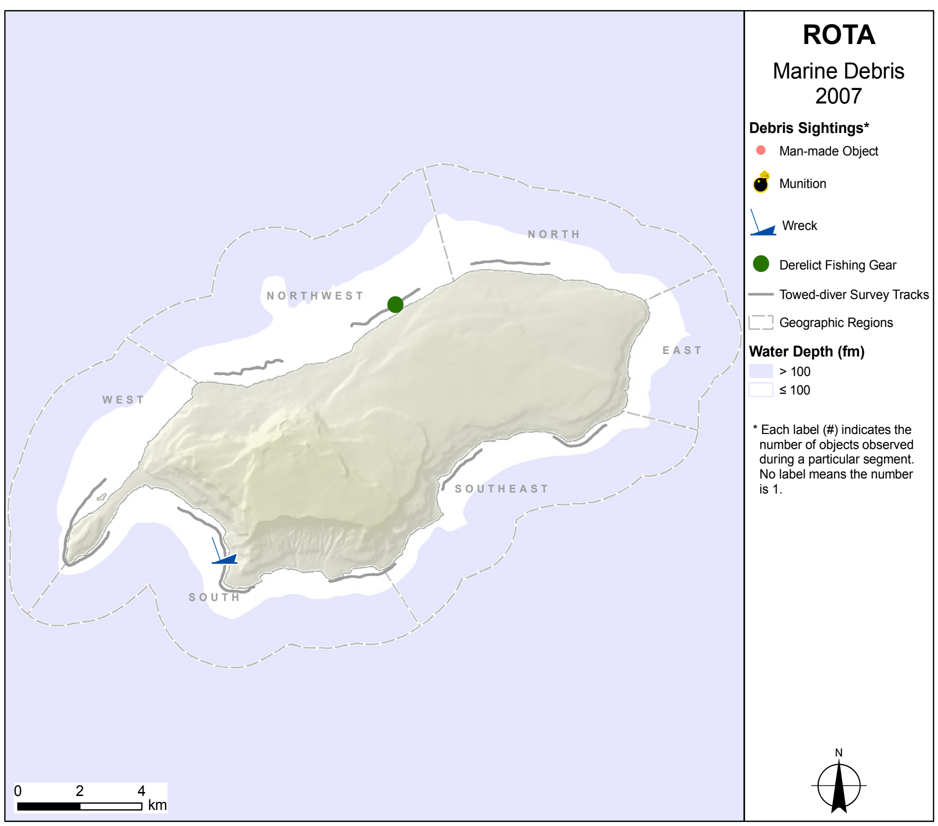
During MARAMP 2005, sightings of 1 wreck and 1 man-made object were recorded in the 11 towed-diver surveys conducted on forereef habitats at Rota (Fig. 5.9.1b). The wreck was observed in the south region, and the man-made object was identified as an anchor in the north region. No sightings of munitions or derelict fishing gear were recorded.

Figure 5.9.1b. Qualitative observations of marine debris from towed-diver benthic surveys of forereef habitats conducted at Rota during MARAMP 2005. Symbols indicate the presence of specific debris types.




During MARAMP 2007, 1 wreck sighting and 1 sighting of derelict fishing gear were recorded in the 10 towed-diver surveys conducted on forereef habitats at Rota (Fig. 5.9.1c). The wreck was noted in the south region. A fishing line was observed in the northwest region. No munitions or other man-made objects were identified.

Figure 5.9.1c. Qualitative observations of marine debris from towed-diver benthic surveys of forereef habitats conducted at Rota during MARAMP 2007. Symbols indicate the presence of specific debris types.



Observations of debris are positive identifications, but absence of reports does not imply lack of debris. Since methods for observing marine debris varied between MARAMP surveys in 2003, 2005, and 2007, temporal comparisons are not appropriate. Debris sightings were recorded differently—with sightings in 2003 recorded as a direct part of diver observational methods and sightings in 2005 and 2007 recorded solely as incidental observations by the towed divers in their observer comments. One constant between the 3 survey periods is worth mentioning: the presence of 1 or more shipwrecks in Sasanhaya Bay in the south region.

## 5.10 Ecosystem Integration

The spatial distributions and temporal patterns of individual coral reef ecosystem components around the island of Rota are discussed in the individual, discipline-specific sections of this chapter. In this section, key ecological and environmental aspects are considered concurrently to identify potential relationships between various ecosystem components. Biological information from towed-diver surveys was integrated to derive 3 composite indices that provide assessments of the relative ecological conditions of forereef habitats in the 4 populated, southern islands of Guam, Rota, Tinian, and Saipan.

The *Benthic Condition Index for Guam, Rota, Tinian, and Saipan* was derived by equally weighting observations of the following 5 parameters from towed-diver benthic surveys around these 4 islands: cover of live hard corals, stressed corals, macroalgae, and crustose coralline red algae and density of COTS. *The Fish Condition Index for Guam, Rota, Tinian, and Saipan* was derived from 2 equally weighted parameters from towed-diver fish surveys: density and biomass of large fishes (≥ 50 cm in TL). The overall *Coral Reef Condition Index for Guam, Rota, Tinian, and Saipan* was derived from an equal weighting of these benthic and fish indices. These condition indices were calculated using ranks assigned to the biological variables from towed-diver surveys conducted around Rota, relative to all surveys around the 4 populated, southern islands for each survey year. To indicate changes in these ranks between survey years, these indices were visualized on a map within survey areas, which are represented by color-coded and irregular polygonal buffers derived from towed-diver-survey tracks that overlapped in 2005 and 2007 (towed-diver-survey tracks were often similar but not exactly the same in each survey year). For more details about the methodology behind these indices, see Chapter 2: "Methods and Operational Background," Section 2.5: "Ecosystem Integration." Each of these 3 condition indices for Rota is presented on a map in Figure 5.10b. Reef condition indices for the entire Mariana Archipelago are presented in Chapter 3: "Archipelagic Comparisons," providing ranks for Rota as well as the other 13 islands of the Mariana Archipelago covered in this report.

MARAMP surveys notably have revealed low levels of live-hard-coral cover at Rota (Fig. 5.10a), relative to values observed around the other populated, southern islands. For example, in 2005, overall mean live coral cover for Rota was 6% (SE 1) from towed-diver surveys, compared to 9% (SE 1.1) for Tinian, 11% (SE 1) for Saipan, and 23% (SE 1.2) for Guam. Similarly, in 2007, overall mean live coral cover for Rota was 4% (SE 1), compared to values > 8% for the other 3 islands. A number of factors can influence abundance of corals; however, none of the data obtained by the CRED provide a clear explanation for the differences observed between Rota and Tinian, Guam, and Saipan.

All of the towed-diver surveys conducted at Rota recorded areas dominated by macroalgae (as seen in a photograph of a shipwreck in Sasanhaya Bay, Fig. 5.10c), with some soft corals and sponges and extensive cyanobacteria in the south and west regions. The most commonly observed macroalgal genera at Rota were *Padina*, *Halimeda*, and *Microdictyon.* Despite this apparent algal dominance, the overall mean cover of macroalgae or turf algae was no higher at Rota than at Guam, Tinian, or Saipan.

Documented anthropogenic impacts known to negatively affect abundance of live corals are less severe at Rota than at Saipan and Guam, and Rota has less pressure from human population and associated activities than do those two islands. Although watershed issues are known to reduce water quality in some locations at Rota, such as Talakhaya Bay, and impaired water quality has been documented at several sites (Fig. 5.10a), overall water quality around Rota is considered excellent (Bearden et al. 2008). Monitoring by the CNMI Division of Environmental Quality (DEQ) revealed that examined reefs were broadly healthy (Bearden et al. 2008). Similarly, although high densities of COTS in 2003 and areas of stressed coral have been recorded in some locations at Rota, these observations appear no more numerous than at the other southern islands.

Subtle differences between the geomorphology of the shallow habitats around Rota versus around Guam and Tinian may exist, but they are not discernable from CRED acoustic data, since benthic habitat mapping is not yet complete around Rota. Riegl and Dodge (2008) noted the absence of substantial modern deposition in some areas around Rota and described shallow habitats as small massive corals occurring directly on Pleistocene (2.6 million to 11,550 years ago) limestone and the size of framework building corals as limited by environmental factors. Such environments tend to naturally support relatively low levels of live coral cover because of the morphology of the corals present.

Since there is no obvious present-day cause, the low coral cover observed at Rota may be a result of past events. For example, an extensive outbreak of COTS occurred around the southern islands of the Mariana Archipelago in 1968, resulting in extensive coral mortality (Tsuda 1972; Quinn and Kojis 2003). While Saipan and Guam had control programs to remove COTS, such management measures historically have not been implemented at Rota, Tinian, or Aguijan.

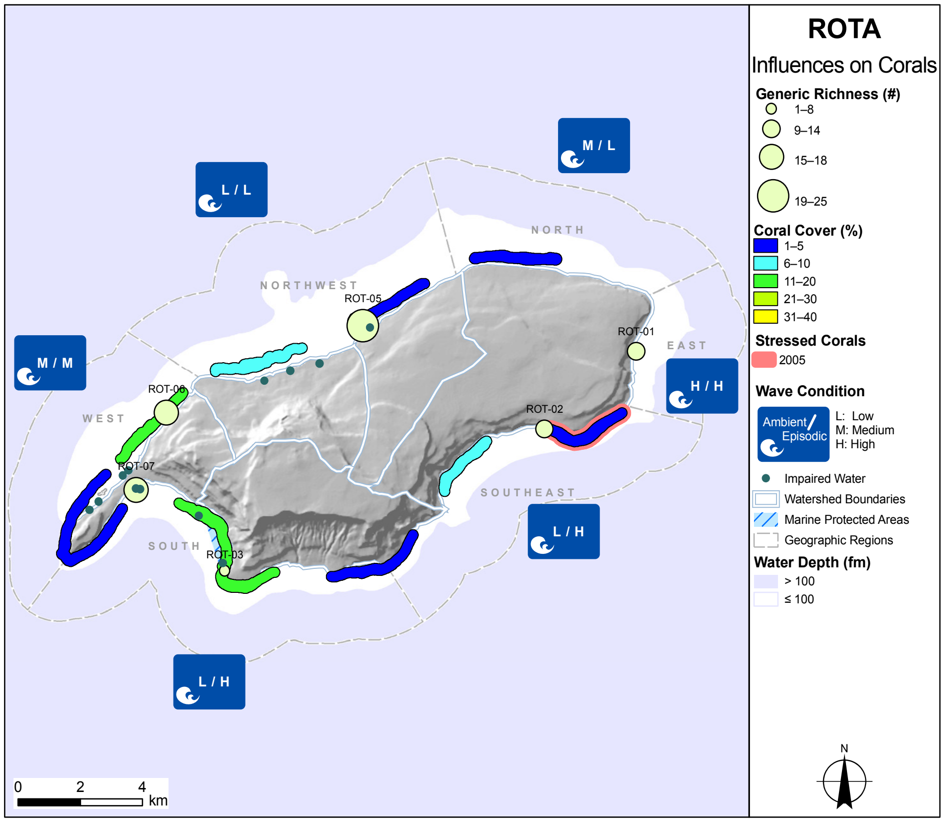



**Figure 5.10a.** Cover (%) observations of live and stressed corals from towed-diver surveys and generic richness from REA surveys conducted on forereef habitats at Rota during MARAMP 2005 and 2007, presented with watersheds and impaired water sites (M Pangelinan, CNMI Department of Land and Natural Resources, pers. comm.; Bearden et al. 2008). Values of coral cover and generic richness represent averages of data from both survey years, where available; otherwise values represent data from the single year surveyed. Towed-diver-survey areas combine overlapping survey tracks for both MARAMP survey years. Colored outlines represent areas where estimates of stressed-coral cover were > 10%. A large, blue icon indicates the level of ambient and episodic wave exposure for each geographic region.

In addition to likely impacts from COTS, Rota has been subject to a number of episodes of coral bleaching, including one episode in 2002 when bleaching was observed in corals at depths of up to 18 m (Richmond et al. 2002). The coral bleaching threshold is defined as 1°C above the monthly maximum climatological mean. In situ data from an SST buoy deployed at mooring site ROT-002 in Sasanhaya Bay in the south region shows that SST there surpassed the bleaching threshold multiple times during the summer months of 2003–2006, with a particularly warm episode in September 2006 (see Figure 5.4.2c in Section 5.4: “Oceanography and Water Quality;” for place-names and their locations, see Figure 5.2a in Section 5.2: “Survey Effort”). This evidence suggests that the reefs there experience considerable thermal stress on a variety of time scales, although this area in Sasanhaya Bay is highly sheltered from prevailing trade winds and their associated swell and, therefore, is likely to have temperatures that are warmer than at other locations at Rota. This thermal stress may have been a potential cause of observed differences in coral cover between MARAMP survey periods. Bleaching was observed during REA surveys conducted at Rota in 2007.

Overall, the ranks for reefs at Rota in the calculated *Benthic Condition Index for Guam, Rota, Tinian, and Saipan* (Fig. 5.10b) ranged from low to high in both 2005 and 2007. For most surveyed locations at Rota, ranks in the *Benthic Condition Index* were the same or higher in 2007 compared to ranks in 2005. In some cases, this pattern was a result of a change in one or more of the index parameters, such as increased cover of crustose coralline red algae or decreased COTS density. At many locations, however, one or more index components changed in a direction that would suggest a decline in actual benthic condition; for example, lower values of live coral cover and higher levels of stressed-coral cover were observed. Still, in these instances where observations suggest that the overall benthic conditions at a specific location has dropped, it declined to a lesser extent than at other locations around the populated, southern islands.

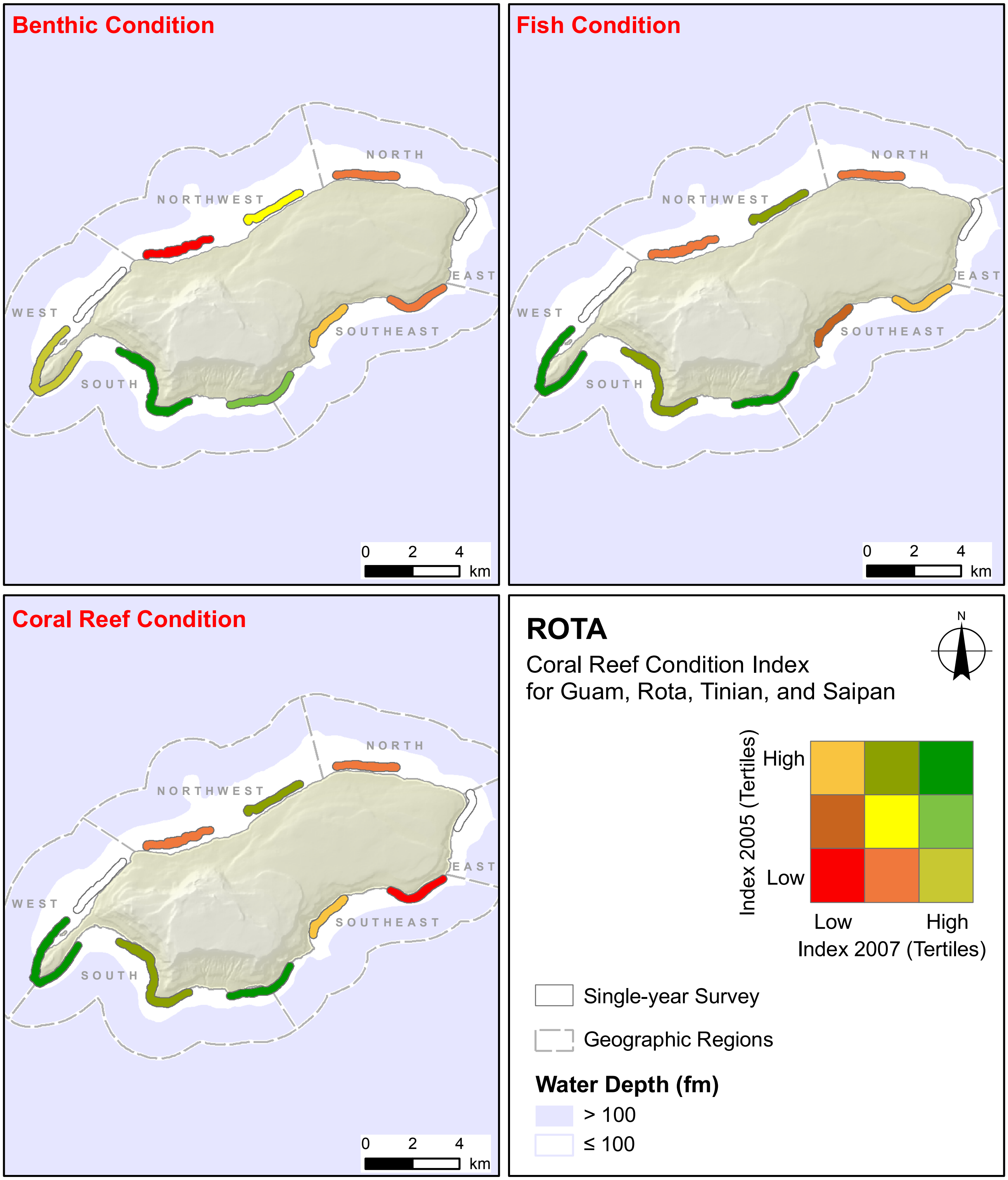



**Figure 5.10b.** The *Coral Reef Condition Index for Guam, Rota, Tinian, and Saipan*, as well as the associated *Benthic Condition Index* and *Fish Condition Index*, reflects the condition of the benthic and fish communities and their integrated ecosystem for each towed-diver-survey area, *relative to other survey areas around the 4 populated, southern islands*. These maps indicate changes in index ranks between MARAMP 2005 and 2007 for towed-diver-survey areas at Rota. Survey areas are represented by irregular polygonal buffers derived from towed-diver-survey tracks that overlapped in 2005 and 2007. No index value is calculated for areas with only one year of survey data. A high rank means superior condition relative to other survey areas around the 4 populated, southern islands. The survey area around this island's peninsula in the west and south regions, for example, has a high rank for both 2005 (y-axis) and 2007 (x-axis) and, thus, is assigned the bright-green color that corresponds to the top-right square in the legend. The position of the horizontal bar above the midline in this square also reflects that this survey area maintained a high rank in both years.

### *Sasanhaya Bay*

Although the overall abundance of live corals was low at Rota, high levels of coral cover were observed along the eastern edge of Sasanhaya Bay within the Sasanhaya Fish Reserve, an MPA that includes Coral Gardens. Estimates of live coral cover from towed-diver surveys conducted in this area were consistently high through the 3 MARAMP survey years, compared to other areas at Rota. In 2003, the highest mean live coral cover in this survey area was 24% over 7 segments, which included 32% for 3 of those consecutive segments, compared to an islandwide mean of 9% (SE 1). Similarly, in 2005 and 2007, the highest mean cover values recorded for 3 consecutive segments were 49% and 58%, and the overall means were 6% (SE 1) and 4% (SE 1). In 2007, the single year when the line-point-intercept method was used to assess live coral cover at REA sites at Rota, the highest coral cover of 34% was observed at ROT-03, also located in Coral Gardens. This survey location was the only area at Rota that showed high coral cover during each of the 3 MARAMP survey periods, although the extent of the area of high coral cover was very restricted, covering less than 1 km of surveyed distance. This area is well sheltered from trade wind waves, allowing for coral cover that was higher there than at more exposed locations along the southeastern and eastern sides of Rota. Although high coral cover was observed at ROT-03, the generic richness recorded at this site in 2007 was only 7, the lowest number of genera per site observed at Rota. This sampled coral community was dominated by corals of the genus *Porites*, predominantly *P. rus* and *P. lichen* and occasionally *P. lobata*. Coral colonies of this genus formed large pillars, extending upward ~ 6 m from the bottom of the seafloor and creating a highly complex habitat with numerous overhangs and crevices.

This well-developed coral community at Coral Gardens sits within a wider reef area observed to have low to moderate levels of coral cover, compared to other areas surveyed around the 4 populated, southern islands. High ranks in the *Benthic Condition Index* were calculated for this area in both 2005 and 2007 (Fig. 5.10b). These high ranks are attributable to the relatively low stressed-coral cover, low COTS density, and moderate abundance of crustose coralline red algae observed in this area, despite the low to moderate coral cover recorded there.

The low coral-cover values found outside of the Coral Gardens area in Sasanhaya Bay and the low generic richness at ROT-03 both likely result from a number of different factors over the past 50 years. As discussed previously, similar to reefs around Saipan and Tinian, reefs at Rota were affected by an outbreak of COTS in 1968 that significantly affected coral communities and greatly reduced live coral cover there. Observers shortly after that outbreak noted that “luxuriant reefs that had previously thrived in [Sasanhaya] Bay…were just drab foundations” (Tsuda et al. 1971, cited in Quinn and Kojis 2003). About 32 years later, during MARAMP 2003, divers reported the continued presence of large areas of upstanding but dead coral in Sasanhaya Bay. Tsuda et al. (1971, cited in Quinn and Kojis 2003) also reported that the species *P. rus* appeared unaffected by the COTS outbreak. This apparent resistance to COTS predation had been previously noted by Goreau (1972). This major COTS outbreak, along with subsequent COTS outbreaks, may have permanently altered the reef composition in this area, resulting in observations there of high coral cover in limited areas and low-diversity, *Porites*-dominated reefs during subsequent MARAMP and other surveys. As noted in the previous section, oceanographic data suggests that reefs in Sasanhaya Bay have experienced considerable thermal stress on a variety of time scales.

Another factor that may affect coral communities in Sasanhaya Bay is the presence of at least 5 shipwrecks (Fig. 5.10c). The direct physical impact of shipwrecks can damage reefs as can the leaching of foreign compounds from wrecks into the surrounding environment, as has been documented at Rose Atoll in American Samoa, where rust from a steel shipwreck caused cyanobacteria blooms and changes in the coral reef environment (Schroeder et al. 2008). Three of the Sasanhaya Bay wrecks are wooden Japanese submarine chasers from WWII, one of which lies in Coral Gardens. Significant damage to the coral reef community in Sasanhaya Bay occurred in 1996, as a result of a powerful detonation of the wreck in Coral Gardens performed by the U.S. Navy at the request of the CNMI Emergency Management Office (Starmer 2005). Aside from direct effects from the explosion, subsequent sediment plumes reportedly caused considerable damage that was further exacerbated by the passage of 2 typhoons, which together affected an area of some 29,000 $m^2$ (Starmer 2005). In central Sasanhaya Bay, 2 steel Chinese smuggling vessels, one of which has 7 propellers, were sunk in 1999 in a sandy area as dive targets to take recreational diving stress off Coral Gardens.

Although this bay includes the Sasanhaya Fish Reserve and a high-quality benthic community relative to the other populated, southern islands of the Mariana Archipelago, the rank for this area in the Fish Condition Index for Guam, Rota, Tinian, and Saipan was not the highest one observed for Rota (Fig. 5.10b). The Fish Condition Index rank for this survey area in 2005 was high, a result of large-fish biomass and density estimates that were higher than levels observed at the other 3 islands in the index, but the rank in 2007 declined to medium because this area's fish biomass and density dropped while estimates for other survey areas around the populated, southern islands improved. Biomass of large fishes (≥ 50 cm in TL), based on towed-diver surveys, was low in this area and overall at Rota in both 2005 and 2007, compared to results at other islands in the Mariana Archipelago, and dominated by parrotfishes (Scaridae) and barracudas (Sphyraenidae). In both 2003 and 2005, a shark was sighted in this area. The highest mean values of large-fish biomass were observed in the west and northwest regions (Fig. 5.10d). Meanwhile, results from the REA site in Sasanhaya Bay, ROT-03, in the 3 MARAMP survey years suggested that fish biomass was not higher there than at other REA sites surveyed at Rota that did not benefit from fisheries protection in an MPA. Other studies have reported some recovery of fish communities within this reserve (Starmer et al. 2008). Note that the southern coast of Rota is readily accessible from both the West and East Harbors, is relatively well protected from prevailing winds, and has one of the higher human population densities on this island.

**Figure 5.10c.** Shipwreck within Sasanhaya Bay. *NOAA photo by Kevin Lino*

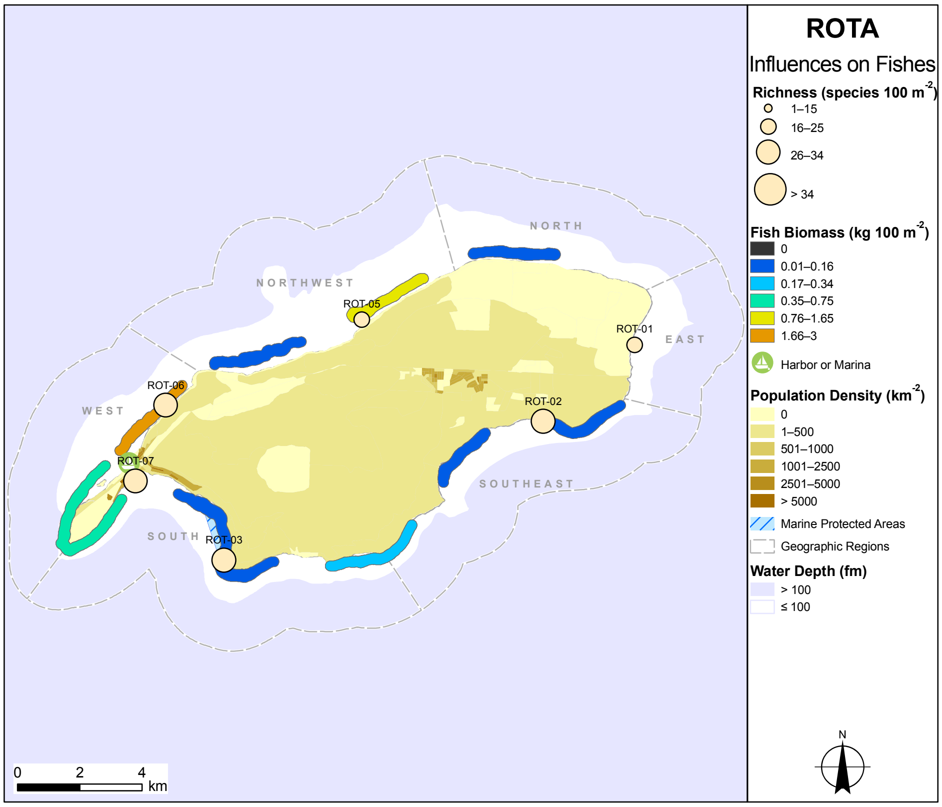



**Figure 5.10d.** Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m$^{-2}$) from towed-diver surveys and species richness from REA surveys conducted on forereef habitats at Rota during MARAMP 2005 and 2007, presented over a human population density map (U.S. Bureau of the Census 2003, 2008). Biomass and richness values represent averages of data from both survey years, but, if surveys were conducted during one year only, values represent data from that single year. Towed-diver-survey areas combine overlapping survey tracks for both MARAMP survey years; survey tracks are often similar but not necessarily the same between survey years.

## 5.11 Summary

This section presents an overview of the status of coral reef ecosystems around the island of Rota as well as some of the key natural processes and anthropogenic activities influencing coral reefs around this island. MARAMP integrated ecosystem observations provide a broad range of information: bathymetry and geomorphology, oceanography and water quality, and biological observations of corals, algae, fishes, and benthic macroinvertebrates along the forereef habitats around Rota. Methodologies and their limitations are discussed in detail in Chapter 2: "Methods and Operational Background," and specific limitations of the data or analyses presented in this Rota chapter are included in the appropriate discipline sections. Methods information and technique constraints should be considered when evaluating the usefulness and validity of the data and analyses in this chapter.

To simplify interpretation of ecosystem conditions around Rota, a *Benthic Condition Index*, a *Fish Condition Index*, and an integrated *Coral Reef Condition Index* were developed to reflect ecosystem conditions at specific locations around Rota, relative to locations around the 4 populated, southern islands of Guam, Rota, Tinian, and Saipan and based on MARAMP 2005 and 2007 surveys only (see Section 5.10: "Ecosystem Integration"). By synthesizing large amounts of complex, interdisciplinary information, these reef condition indices assist resource managers in identifying potential relationships between various ecosystem components. The conditions of the fish and benthic communities and the overall ecosystem around Rota, relative to all the other islands in the Mariana Archipelago, are discussed in Chapter 3: "Archipelagic Comparisons."

The following summary highlights the key attributes of the coral reef ecosystems around Rota (for place-names and their locations, see Figure 5.2a in Section 5.2: "Survey Effort"):

- Rota is the fourth largest island in the Mariana Archipelago but in 2000 contained only 1.5% of the total human population of the Mariana Archipelago.
- Popular beaches are located mainly in the northwest region, and most dive sites are located in the south, west, and northwest regions. Steep cliffs on the southern and southeastern coasts reduce accessibility there.
- Rota is surrounded by narrow fringing reefs and shelves. The shallowest waters mapped around Rota reveal a series of narrow shelves, likely related to previous sea level stands. Northwest and west of Rota, shelves are narrow, but in Sasanhaya Bay wider shelves are present. Mounds distinguishable in the map of seabed slope at depths up to 50–80 m may be interpreted as coral mounds.
- Wave model output shows ambient trade wind swells impacting the north and east and to a lesser extent the southeast. Episodic wave energy from storm tracks impacts the south and southeast and to a lesser extent the east and west.
- SST in the south and northwest regions surpassed the bleaching threshold in September 2006.
- Overall abundance of live corals for Rota was low from both towed-diver and REA surveys, compared to the rest of the Mariana Archipelago. The overall sample mean for coral cover from REA surveys was 12.4% in 2007. Overall mean for cover of live hard corals from towed-diver surveys was 9% in 2003, 6% in 2005, and 4% in 2007.
- Current levels of affects from human activities or other stressors did not appear to explain the low live coral cover observed at Rota, compared to Guam, Saipan, and Tinian. The low cover of live corals may result from subtle differences in geomorphology or historic impacts, such as COTS outbreaks, coral bleaching, and typhoons.
- On the eastern edge of Sasanhaya Bay, towed-diver surveys suggested consistently high coral cover in Coral Gardens, a marine protected area, with mean coral cover over 3 consecutive segments estimated at 32%, 49%, and 58% in 2003, 2005, and 2007.
- Bleaching was the only disease state observed at Rota in 2007, the only year in which disease surveys were conducted, and was found on *Astreopora* colonies. Five cases of bleaching were documented, translating to a mean prevalence of coral disease of 0.05%. Additionally, predation attributable to COTS or *Drupella* snails was observed, and 40% of predation cases occurred on *Astreopora* colonies.
- Overall mean macroalgal cover, from towed-diver surveys conducted at Rota, was nearly identical in 2003 and 2005 but slightly lower in 2007. This difference may result from seasonal shifts of algal populations. High macroalgal cover was consistently recorded during surveys in the north and east regions in the 3 MARAMP survey years.

- The highest cover value for crustose coralline red algae was consistently recorded during the towed-diver survey completed at the western tip of this island. The survey with the lowest cover level was consistently located in the north region, near Asuzudo and Mochon Points, although, in 2005, no crustose coralline red algae were observed during the survey conducted in the southeast region west of Puntan Sagua`gahga.
- Only one type of coralline-algal disease was documented at Rota: coralline lethal orange disease, which was present at 5 of the 6 REA sites surveyed.
- Overall large-fish (≥ 50 cm in TL) biomass, from towed-diver surveys, declined to 0.14 kg 100 $m^{-2}$ in 2007 from 0.49 kg 100 $m^{-2}$ and 0.48 kg 100 $m^{-2}$ in 2003 and 2005. REA fish surveys conducted during the 3 MARAMP survey periods showed no clear spatial pattern at Rota; however, the highest mean total fish biomass in 2005 and 2007 was seen at ROT-02, located west of Puntan Sagua`gahga in the southeast region. Fish biomass at Rota was low, relative to the rest of the Mariana Archipelago, with mean total fish biomass of 4.07 kg 100 $m^{-2}$ for the 3 MARAMP survey years.
- A low abundance of giant clams was recorded around Rota during the 3 MARAMP survey periods, compared to the rest of the Mariana Archipelago.
- In 2003, towed-diver benthic surveys found that COTS were ubiquitous around Rota. However, COTS were most abundant in the southeast, south, and west regions. Localized areas where potential COTS outbreaks may have been occurring were observed near Puntans Taipingot, Sailigai, and Malilok. Observed COTS densities suggest that the COTS population around Rota was much smaller in 2005 than in 2003, and densities were greatest around Puntan Taipingot in 2005. By 2007, this COTS population appears to have declined further.
- Towed-diver benthic surveys revealed higher sea cucumber abundance in the south and southeast regions than in other regions around Rota during the 3 MARAMP survey periods.

This page was left blank intentionally